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JOURNAL

OF

THE ROYAL SOCIETY

OF

WESTERN AUSTRALIA, INC.

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The Authors of Papers are alone responsible for the statements
and
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THE ROYAL SOCIETY OF WESTERN AUSTRALIA (INC.).

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VOLUME XXVI.

The Royal Society of Western Australia (Inc.).

ANNUAL REPORT OF COUNCIL FOR THE YEAR ENDED 30TH JUNE, 1940.

Ladies and Gentlemen,

Your Council begs to submit the following report for the year ended 30th June, 1940.

Council.—The Council of the Royal Society met on six occasions, and the Executive Committee on six occasions.

On account of the large amount of routine business to be considered at meetings an Executive Committee was appointed as in 1938–39 to deal with such matters and report to Council.

Finance.—The General Fund shows a balance of £105 4s. 5d. The Endowment Fund now amounts to £290 15s. 0d. Assets are now £436 3s. 1d. compared with £391 at the same time last year. The satisfactory condition of the Society's finances reflects the careful management of the Hon. Treasurer, Dr. E. M. Watson.

Membership.—Membership remains almost the same as at the commencement of the year. Two Ordinary Members and ten Associate Members have resigned and one Ordinary Member has transferred to Associate Membership. The names of one Ordinary Member and three Associates have been removed from the register in accordance with Rule 6.

We regret to record the loss by death of four of our members—Dr. E. S. Simpson, Mr. H. B. Gates, Mr. J. M. Limb and Mr. H. J. Urquhart. Dr. Simpson was one of the founders of the Western Australian Natural History and Science Society and of the Royal Society which grew out of it, and he occupied at different times the position of President of both of these Societies.

Members elected during the year includes one Life Member, eleven Ordinary Members, five Associate and three Students.

There are at present 153 members of the Society made up as follows :—

Honorary Members	7
Corresponding Members	7
Life Member	1
Ordinary Members	92
Associate Members	38
Student Members	8

Lectures.—In addition to the communication of papers to the Society a number of important lectures covering a wide field of scientific interest were delivered to members of the Society. These were :—

"Parasitic Worms," by Dr. H. W. Bennetts and others.
"Whales and Dolphins," by Mr. L. Glauert.
"Automatic Temperature Control," by Mr. V. Hopper.
"The Turpentine Bush," by Messrs. Gardner and Hill.
"Fact Finding in Fisheries," by Dr. H. Thompson.
"Impressions gained on a Visit to America," by Mr. F. G. Forman.

Excursions.—Two interesting and well attended excursions were held during the year. One to the Tannin Extract Plant at Boddington, led by Mr. Hughes, provided most members with their first experience of this industry. The other to the Firebrick quarries at Clackline, led by Mr. H. A. Ellis, enabled members to see something of the Pre-Cambrian geology of this area and the manufacture of refractory bricks.

Journal.—The publication of volume 25 has been completed and the Journal distributed among members and scientific institutions with which the Society is in exchange.

During the year thirteen papers were presented to the Society for publication in the Journal.

The Government Printer and his staff have co-operated whole-heartedly with the Hon. Editor, Mr. B. L. Southern, and the Council desires to thank them sincerely. Mr. Southern remains in the office of Hon. Editor and the Society is indebted to him for continuing to place his experience in this work at its disposal.

Library.—The Society has now entered into exchange of publications with a total of 182 scientific institutions of which 54 are in Australia, 16 in the United Kingdom, 23 in other parts of the British Empire, 46 in North and South America, 40 on the Continent of Europe and three in Asia.

During the year Mr. A. Gibb Maitland donated a large number of volumes (including almost complete runs of : The Mineralogical Magazine, vols. 1–20 ; Natural Science, a complete set of 15 volumes ; Science Progress, vols. 1–15 ; and The Journal of Geology, vols. 1–28). The Council wishes to express its thanks to Mr. Gibb Maitland for these very valuable donations to the Society's library.

The thanks of the Society are due to Mr. Glauert and Mrs. Jenkins for the work that they have put into the Library so that information may be available to members when required.

Housing of the Society.—Your Council has decided that, if possible, the Society should be housed along with the other Professional Societies in the Gledden Buildings. To this end, negotiations are at present being made with the Institute of Engineers.

H. BOWLEY,
President.

REX. T. PRIDER,
C. H. F. JENKINS,
Joint Hon. Secretaries.

THE ROYAL SOCIETY OF WESTERN AUSTRALIA, INCORPORATED.—*Statement of Receipts and Payments for the Year ended 30th June, 1940.*

General Fund

Receipts.	£ s. d.	£ s. d.
General Fund—		
Balance at 1st July, 1939		96 8 5
Interest, 1938–39		1 14 1
Subscriptions—To 30th June, 1940	116 15 3	
,, In advance	6 0 9	
,, Life Membership	21 0 0	
		143 16 0
Government Grant		100 0 0
Authors' Reprints and Half Cost of Blocks		40 17 2
Endowment Fund—Fixed Deposit	250 0 0	
,, ,, Interest on Fixed Deposits	8 5 0	
		258 5 0
Excursion—Boddington	4 1 0	
,, Clackline	2 5 0	
		6 6 0
Other Receipts		1 4 3
		£648 10 11

Payments.	£ s. d.	£ s. d.
Petty Expenses, including Postages, etc.		5 16 6
Clerical Assistance		2 13 6
Museum Trustees—Rent and Attendance		15 17 0
G.P.O. Box Rent		3 0 0
Annual Meeting—Rent	1 11 6	
,, ,, Catering	3 7 6	
		4 19 0
Ordinary Meetings—Catering		10 5 0
Library—Bookbinding		12 5 0
Government Printer—		
Vol. XXV., Printing	134 9 11	
,, Blocks	34 4 3	
Miscellaneous Printing	8 7 0	
		177 1 2
Editor's Honorarium		15 15 0
Excursion—Boddington	5 12 5	
,, Clackline	2 0 6	
		7 12 11
Endowment Fund—War Savings Certificates		200 0 0
Life Membership Fund—Commonwealth Savings Bank, Fixed Deposit		20 0 0
Other Payments		2 6 5
Balance at 30th June, 1940—Endowment Fund	65 15 0	
,, ,, ,, General Fund	105 4 5	
		170 19 5
		£648 10 11

Medal Fund

	£ s. d.		£ s. d.
Balance at 1st July, 1939	19 16 2	Balance at 30th June, 1940	20 3 8
Interest, 1938–39	0 7 6		
	£20 3 8		£20 3 8

Endowment Fund

	£ s. d.	£ s. d.		£ s. d.
Balance as shown at 1st July, 1939		275 0 0		
Interest—1938–39	7 10 0			
,, 1939–40	8 5 0			
		15 15 0	Balance at 30th June, 1940	290 15 0
		£290 15 0		£290 15 0

Life Membership Fund

	£ s. d.		£ s. d.
Transfer from General Fund	20 0 0	Balance at 30th June, 1940	20 0 0
	£20 0 0		£20 0 0

Summary of Funds at 30th June, 1940.

	£ s. d.	£ s. d.
Credit Balance, General Fund		105 4 5
,, ,, Medal Fund		20 3 8
,, ,, Endowment Fund—		
War Savings Certificates	200 0 0	
Commonwealth Savings Bank, Fixed Deposit	25 0 0	
Held in Commonwealth Savings Bank, Account No. S4059	65 15 0	
		290 15 0
,, ,, Life Membership Fund		20 0 0
		£436 3 1

Audited and found in agreement with books, receipts, and vouchers produced. We consider this is a true statement of the Royal Society's Accounts.

1st July, 1940.

E. M. WATSON, Hon. Treasurer.

J. SHEARER,
W. F. COLE,
Hon. Auditors.

ABSTRACT OF PROCEEDINGS, 1939-1940.

11th July, 1939—

Annual General Meeting held in Gledden Hall. Presidential Address: "Mineral Provinces and Metallogenetic Epochs in Western Australia," by Dr. E. S. Simpson.

8th August, 1939—

Papers—"The Essential Oils of Western Australian Eucalypts, Part VI." Dr. E. M. Watson and Mr. G. E. Marshall.

"Platyhelminth and Acanthacephalon Parasites of Local Shags," Miss O. M. Goss.

Address—"Importance of Internal Parasites from a Veterinary Viewpoint," Dr. H. W. Bennetts.

12th September, 1939—

Papers—"Marine Jurassic in North-West Basin, Western Australia," Dr. C. Teichert.

"A New Fossil (Solenoporacea) from the Jurassic Rocks of Western Australia," Professor J. Pia, communicated by Dr. Teichert.

"On Upper Cretaceous (Maestrichtian) Ammoidea from Western Australia," by Dr. L. F. Spath, communicated by Dr. Teichert.

Address—"Whales and Dolphins," Mr. L. Glauert.

10th October, 1939—

Paper—"Cambrian Basalts from the East Kimberley," Professor E. de C. Clarke and Dr. A. B. Edwards, communicated by Professor Clarke.

Address—"Automatic Temperature Control," Mr. V. Hopper.

14th November, 1939—

Papers—"Actinosiphonate Cephalopods (Cyrtoceroidea) from the Devonian of Australia," Dr. C. T. Teichert.

"The Occurrence of Xenotine in Western Australia," Mr. J. N. A. Grace.

"A Note on the Age Relations of the Porphyries and Porphyrites at Kalgoorlie," Dr. R. T. Prider.

12th December, 1939—

Paper—"Marine Jurassic of East Indian Affinities at Broome, N.W. Australia," Dr. C. Teichert.

Exhibits—Special exhibits were arranged as follows:—

"Some Examples of Abnormal Botanical Growth," Miss A. Baird.

"Samples from the Langley Park Bore and a comparison with King's Park Bore No. 2," Dr. D. Carroll.

"Complement Fixation Test for Pleuro-pneumonia," Dr. H. W. Bennetts.

"Some Uses of the Ultra Violet Lamp," Mr. H. E. Hill.

"Some Crystallographic Examples," Dr. R. T. Prider.

"Two Species of Plants Producing Cotton," Mr. C. A. Gardner.

12th March, 1940—

Paper—"Analysis of Soil Colloids by X-Ray Diffraction Methods," Mr. J. Shearer.

Address—"Work of the Department of Information," Mr. I. T. Birtwistle.

9th April, 1940—

Address—"Scientific Exploitation of Fisheries," Dr. H. Thompson.

14th May, 1940—

Paper—X-Ray Analysis of some Soil Colloids from Tasmania," Mr. J. Shearer.

Address—"Harvard University," Mr. F. G. Forman.

11th June, 1940—

Papers—"The Geology and Physiography of the Malkup Area," Mr. W. F. Cole.

"Notes on the Load carried by Flood Waters in the South-West," Professor E. de C. Clarke.

CHANGE OF ADDRESS.

Will members and institutions which exchange publications with the Society please note the change of postal address to—

Royal Society of Western Australia,
7th Floor,
Gledden Buildings,
Perth,
Western Australia.

LIBRARY.

Members wishing to use the library are advised, for the time being, that they may do so on week days between 9 a.m. and 5 p.m., Saturdays 9 a.m. and 12 noon. Arrangements to borrow a key for other periods may be made directly with either—

Mrs. Jenkins, Tel. MU. 231.

Mr. Jenkins, c/o. Department of Agriculture, Tel. B. 9111. or

Dr. Prider, c/o. University, Tel. WM. 1911.

JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

VOLUME XXVI.

1.—PLATYHELMINTH AND ACANTHOCEPHALAN PARASITES OF LOCAL SHAGS.

By OLGA M. GOSS, B.Sc.

Read 8th June, 1939; Published: 28th June, 1940.

INTRODUCTION.

During his investigations into the feeding habits of shags on the Swan River, Dr. Serventy examined a large number of birds, most of which were passed on to the writer to examine for parasites. Three species of shags commonly occur on the Swan River:—

Phalacrocorax varius or the large pied shag.
Phalacrocorax ater or the small black shag.
Microcarbo melanoleucus or the small pied shag.

Number of each species of shag examined for parasites:

P. varius	80 birds.
P. ater	30 birds.
M. melanoleucus	50 birds.

All of these birds harboured at least one species of parasite. Examinations were carried out monthly from January to July. It is rather noteworthy that the parasites were decidedly fewer in number in July than they had been previously. This seems to indicate a seasonal periodicity in the parasites. It was impossible at the time to carry on the investigations to see if this were the case.

One specimen of *Phalacrocorax carbo* from Mandurah was also examined and found to harbour several specimens of the small Cestode.

Nematodes are very numerous in the shags' stomachs.

In all, three Trematodes, two Cestodes and one Acanthocephalan were found in the shags.

TABLE OF SPECIES OF PARASITES FOUND IN EACH SPECIES OF BIRD.

P. varius—*Dilepis minima* sp. nov., *Polymorphus clavatus* sp. nov., a young Trematode.

P. ater—*Paryphostomum phalacrocoracis* sp. nov., *Diplostomum granulosum* sp. nov., *Dilepis minima* sp. nov., *Polymorphus clavatus.*

M. melanoleucus—*Paryphostomum phalacrocoracis* sp. nov., *Dilepis minima* sp. nov., *Dilepis maxima* sp. nov., *Polymorphus clavatus* sp. nov.

In every case the fixative used was Kleinenberg's Picric Acid. Whole mounts were stained with Borax Carmine, and Lithium Carmine. Sections were cut to assist in the working out of the anatomy and were stained with Iron Haematoxylin and Mann's stain.

The species appear to be new as they differ markedly from the descriptions of other species available but it is impossible to be absolutely sure on this point owing to the deficiency of periodicals available for reference. However a study of the Zoological Record makes it appear that no references relevant to the species have been overlooked.

CLASSIFICATION AND DESCRIPTION OF SPECIES.

Class TREMATODA.

SUPERFAMILY **ECHINOSTOMATOIDAE.**

FAMILY **ECHINOSTOMATIDAE.**

Genus **PARYPHOSTOMUM** (Dietz).

Paryphostomum phalacrocoracis sp. nov.

Dietz 1910. Edwards 1927.

Gogate 1934.

Diagnosis of Species.

Size—2.5 — 6.14 mm. long, the breadth equalling about 1/7th—1/8th of this.

Collar Spines—27 in number, in a single row. Ventrally the spines are gathered into two end groups of four spines each which are *broader and shorter* than the remaining nineteen.

Ratio of diameter of oral to ventral sucker = 1 : 4.5 — 6.

Testes—anterior 4-6 lobed (0.47 mm. x 0.47 mm.), posterior 5-7 lobed (0.78 mm. x 0.4 mm.).

Cirrus sac—small (0.24 mm. x 0.06 mm.) and oblique.

The *vitellarium* extends to the base of the ventral sucker and fills the whole of the post-testicular space.

Uterus—moderately coiled.

Eggs—100 or more 0.057 — 0.084 x 0.071 — 0.06 mm. in size.

Host. In the small intestine of *P. ater* and *M. melanoleucus.*

No. present—up to ten per bird.

General Description of Species.

Body elongated varying in length from 2.5 — 6.14 mms. (see fig. 1). Anteriorly in front of the ventral sucker the body is hollowed out ventrally and is thickly beset with small dermal spines which are plentiful ventrally but sparsely developed dorsally. The maximum width which occurs in the region of the testes is 0.8 mm. for a specimen 6.14 mms. long. Unless otherwise stated all measurements will refer to this specimen as it shows all the organs well and all measurements can therefore refer to one specimen only. The measurements were taken in balsam. The head collar (see fig. 2) is well developed and bears a single row of marginal spines, 27 in number and unbroken dorsally. Ventrally the collar spines are gathered into 2 "end groups" of 4 spines each.

Text Fig. 1.

The 8 spines forming the 2 "end groups" are shorter and wider than the remaining 19—their measurements being—

outermost spine from end group—0.1 mm. x 0.03 mm.
and marginal spine—0.13 mm. x 0.023 mm.

Alimentary Canal.—The oral sucker which is sub-terminal is slightly broader than long (0.11 mm. x 0.09 mm.). It is connected with the oval muscular pharynx (0.11 mm. x 0.14 mm.) by the prepharynx (0.07 mm. long) passing on into the comparatively long oesophagus (0.44 mm.) which bifurcates to form the intestinal caecae immediately in front of the ventral sucker. The intestinal caeca terminate a little in front of the posterior end.

The ventral sucker is large and cup shaped—measuring 0.7 x 0.57 mm.—so that the ratio of the diameters of the oral to the ventral sucker is approximately 1:6. In the smaller and more contracted specimens the ratio between these 2 suckers may be as low as 1:4.5.

Excretory System.—The excretory pore is dorsal and near the posterior end. The excretory vesicle is elongated and gives off branches which ramify in the posterior body. It extends to the posterior testis where it divides into two and passes anteriorly (see fig. 3).

Genital Organs.

The genital pore lies between the intestinal bifurcation and the ventral sucker.

Male.—The testes lie one behind the other approximately in the middle of the space between the ventral sucker and the posterior end—the posterior one being larger than the anterior. The anterior testis is 4-6 lobed and measures 0.47 x 0.47 mm. while the posterior is 5-7 lobed and measures 0.78 x 0.4 mm. The cirrus pouch is moderately well developed, oblique to the main axis and measures 0.24 x 0.06 mm. (see figs. 1 & 4).

Female.—The almost spherical germarium (0.21 mm. x 0.19) lies to the right of the middle line anteriorly to the testes. The follicular vitellaria extend back from the ventral sucker in two lateral fields to the posterior testis, behind which they spread out to the middle line. The longitudinal vitelline ducts unite to form transverse ducts which expand medianly to form a vitelline reservoir (0.14 mm. x 0.15 mm.). From here a median duct passes to enter the oviduct which has already received the sperm from the receptaculum seminis. The oviduct passes into the ootype which is surrounded by a large median shell gland complex (0.29 mm. x 0.21 mm.). From here the slightly coiled uterus passes anteriorly to open just posteriorly to the cirrus sac. The eggs are numerous and measure 0.057 mm.—0.084 mm. x 0.071—0.06 mm.) (see figs. 1 & 5).

Relationships.

This species resembles *P. radiatum* (Dujardin) and *P. testitrifolium* (Gogate) in the possession of a single row of collar spines but it differs from *P. testitrifolium* in the shape of the testes which for *P. testitrifolium* are characteristically 3 lobed, in the sizes of the collar spines and in the relative sizes of the constituent parts especially the prepharynx and ventral sucker.

It differs from *P. radiatum* in

1. The ratio of the oral to the ventral sucker, which in *P. radiatum* is 1 : 3 is 1 : 4.5—6.
2. The number of eggs (48 in *P. radiatum* and 100 in *P. phalacrocoracis*).
3. The coilings of the uterus are more numerous.
4. The cirrus sac is smaller.

   etc.

Table 1 shows the various characters of the several species of *Paryphostomum* and may serve to clarify the differences between them.

P. indicum is omitted from the table but it can be easily distinguished from the other species owing to the fact that it possesses 42 collar spines, whereas the other species possess only 27.

TABLE 1.

PARYPHOSTOMUM (Dietz).

——	P. radiatum (Dietz).	P. radiatum (Edwards).	P. segregatum (Dietz).	P. testrifolium (Gogate).	P. phalacrocoracis (sp.nov.).
No. of collar spines	double row 27	single row 27	double row 27	27	single or double row 27.
Size of animal	3·3-6·5mm.	2·3 6mm.	5·75mm.	3·5 5mm.	2·5–6·14mm.
Length of spines 19	0·074–0·102 x 0·0140–0·0204 mm.	0·0885–0·0922 x 0·0188mms.	0·1088–0·1224 x 0·0144–0·0168	0·064 0·101 x 0·03 0·0324	0·086–0·13 x 0·021 0·03mm.
Length of spines 4	0·1052–0·1224 x 0·030–0·034mm.	outermost of group 0·128 x 0·03mm.: other 3, 0·1129 x 0·0188	0·1360–0·1428 x 0·0168 0·0216 (oral prs. can be longer)	0·108 0·115 x 0·044–0·0479	0·093–0·114 x 0·021–0·04mm. (outermost not larger than other three).
Ratio of length to breadth	6–7 : 1	4 5 : 1	....	about 6 : 1	about 7 : 1
Body spines	fore end of body covered	disappear at level of hinder margin of posterior testis. Dorsally as far as posterior border of sucker	....	..	thick anteriorly to ventral sucker—present or absent behind this. (only ventral not dorsal)
Distance between centres of suckers	1/5th of body length	¼–1/5th of body length	....	...	1/5th–1/6th of body length.
Ratio of length of ventral sucker to length of body	.	1 : 10	1 : 9	1 : 10	1 : 9
Ratio of diameter of oral to ventral suckers	1 : 3·5–4	1 : 3	approx. 1 : 3	1 : 4 5	1 : 4·5-6
Prepharynx	0·09-0·18mm.	....	0·034 0·075mm.	0·027mm.	0·07mm. specimen 6·14mm. long.
Pharynx	0·15 0·16 x 0·12–0·13mm.	0·16 x 0·145 mm.	0·156 (spherical) or oval 0·14–0·17 x 0·11–0·15mm.	0·135 x 0·093 mm.	0·11 x 0·14mm.
Oesophagus	....	0·32mm.	....	0·464mm.	0·44mm.
Oral sucker ..	0·10 0·16mm. in diameter	.	0·17–0·18mm. in diameter	..	0·11 x 0·09mm. in diameter.
Anterior Testis	3-7 lobed	4 5 lobed (0·5 x 0·48mm.)	5–7 lobed	3 lobed	4-6 lobed (0·47 x 0·47mm.).
Posterior Testis	3–7 lobed	5 6 lobed (0·55 x 0·55mm.) 2/3rds of body length from anterior end	5–7 lobed	3 lobed	5 7 lobed (0·78 x 0·4mm.) 2/3rds of body length from anterior end.
Post-testicular space	...	1·35mm.			1·7mm.
Germarium	0·11 0·17mm.	0·21mm.	0·17-0·20mm. in diameter	0·17 x 0·165 mm.	0·21 x 0·19mm.
Cirrus Pouch....	Small, almost entirely in front of ventral sucker	0·7 x 0·3 extends back posteriorly to the level of the centre of the ventral sucker	...	0·197 x 0·0945	0·25 x 0·06 extending back to 1/5th of length of ventral sucker.
Uterus	.	few coils	..	short, not very coiled	more coiled.

TABLE 1—*continued.*

	P. radiatum (Dietz).	P. radiatum (Edwards).	P. segregatum (Dietz).	P. testrifolium (Gogate).	P. phalacrocoracis (sp.nov.).
Eggs	...	maximum 48, size 0·08–0·1 x 0·05–0·064 mm.	few, 0·0864 0·0884 x 0·057–0·060mm.	small and numerous 0·0771 x 0·0407	100 or more. size 0·057–0·084 x 0·071–0·06mm.
Shell gland	....	0·22 x 0·194 mm.	. .	0·19 x 0·275 mm.	0·29 x 0·21mm.
Ventral sucker on border of	1st and 2nd ⅓'s of body length	1st and 2nd ⅓'s of body length	....	....	1st and 2nd 1/5th of body length.

Family **STRIGEIDAE.**

Subfamily **POLYCOTYLINAE.**

Genus **DIPLOSTOMUM** (Dubois), 1932.

(syn. *Hemistomum* (Brandes)), 1891.

Diplostomum granulosum sp. nov.

Diagnosis of Species.

Size.—1.23 mm. x 0.61 mm. at widest point, which is anterior. Anterior region is flattened 0.6 x 0.61 mm. The posterior region is cylindrical 0.63 x 0.38 mm.

Ventral sucker.—Slightly smaller than the oral sucker (diam. 0.08 mm.).

Hold fast organ.—Large and bilobed, glandular tissue well developed.

Genitalia.

Male.—Anterior testis assymmetrical—developed on left side—0.21 x 0.16 mm.

Female. —Germarium median.

Vitellarium extends to beyond the ventral sucker in the anterior body. Receptaculum seminis, shell gland and ootype to the right of anterior testis.

Eggs.—Few and large 0.086 x 0.085 mm.

Host.—In the small intestine of *P. ater*—very numerous.

General Description.

This is a small form 1.23 mm. long x 0.61 mm. at its widest point. The general shape is rather triangular, the base of the triangle being anterior, but actually the worm is distinctly divided into two regions, the anterior being flattened and concave ventrally (0.6 mm. x 0.61 mm.) and the posterior cylindrical (0.63 x 0.38 mm).

Anteriorly the worm has a rather 3 lobed appearance due to the development of lateral pseudosuckers flanking the median oral sucker (0.086 mm. in diameter). The pseudosuckers are depressions marking the openings of the ducts of cephalic glands. The elongated and muscular pharynx (0.043 mm. x 0.055 mm.) passes into a short oesophagus (0.043 mm. long) which bifurcates to form the intestinal caecae passing to the posterior end of the body (see fig. 6).

The ventral sucker is slightly smaller than the oral sucker (0.08 mm. in diameter) and is covered over by the hold fast organ. The hold fast organ is large and bilobed and the glandular tissue at its base is very well developed (see fig. 6, 7, 8, and 9).

Genital organs.

Male.—Testes one behind the other. The anterior testis (0.21 mm. x 0.16) is assymmetrical and developed in the left half of the body in the first third of the posterior body. The posterior testis is larger (0.34 x 0.17 mm.) and extends right across the body occupying the second third. It tends to be slightly bilobed. The last third of the posterior body is occupied by the vesicula seminalis which opens to the exterior dorsally about 0.03 mm. from the posterior end (see fig. 6 and 9).

Female.—Ovary (0.16 x 0.1 mm.), oval, median in front of the anterior testis. Vitelline follicles—in both anterior and posterior body. Posteriorly they are practically confined to the lateral and ventral region of the post-testicular region but anteriorly they are better developed. They extend to beyond the intestinal bifurcation and spread out dorsally over the body and extend down to the ovarian region. The vitelline reservoir is well developed and occurs between the two testes. The receptaculum seminis, shell gland and ootype lie to the right of the anterior testis. The uterus passes from the ootype anteriorly to beyond the ovary and then turns posteriorly opening into the genital atrium. The eggs are few and large 0.086 x 0.085 mm. (see fig. 6).

This species differs from all the other members of the genus chiefly in the extent of the hold fast organ which completely covers over the ventral sucker and in the body shape which is characteristically widest right anteriorly. It also differs from the majority of species in that it is broadest anteriorly, the oral sucker is larger than the ventral sucker, the germarium is median and the anterior testis is only developed on the left side.

Family **STERINGOPHORIDAE.**

This is an immature Trematode which probably belongs to the *Steringophoridae*. Only the rudiments of the reproductory organs including the cirrus sac are developed, so that it is impossible to ascertain whether these correspond completely with those of fam. *Steringophoridae* or not. It agrees in all other points with the diagnosis of this family as given by Fuhrmann (1932).

Host.—*P. varius* at the end of the small intestine. Only about half dozen specimens found.

Description.

The worm is 2.3 mm. long x 0.71 mm. at its greatest width (see fig. 10). It is roughly oval in surface view but rather wider anteriorly than posteriorly. The oral sucker is large and circular, being 0.37 mm. in diameter, whilst the ventral sucker is smaller and rather elongated, measuring 0.27 mm. x 0.11 mm. The distance between the centres of the suckers being 0.67 mm.

Alimentary Canal.—A prepharynx is not developed but the pharynx is large, measuring 0.36 mm. long x 0.16 mm. wide. Oesophagus is almost absent. The intestinal branches are very long and convoluted. From the oesophagus on either side they extend anteriorly and then posteriorly to the hinder end.

Excretory System.—The excretory bladder is Y shaped—the stem region extending to immediately below the ventral sucker where it divides into two.

Genitalia.

Male.—The testes occur in the posterior body, the left testis being slightly anterior to the right. The cirrus sac is developed dorsally to the ventral sucker and measures 0.11 mm. x 0.13 mm. The genital pore is slightly displaced to the left of the ventral sucker.

Female.—Germarium is developed anteriorly to the testes and to the right side. To the inner side of this, there is some darkly staining tissue which probably represents the shell gland and there is a strand of darkly staining tissue which passes from this region to the genital pore which probably represents the uterus.

Remarks.

The Fam. *Steringophoridae* have so far only been found in fish and it is probable that these parasites were present in one of the fish eaten by the shags and were not actually parasitising the shags. The fact that they were only found on one occasion although especially searched for on subsequent occasions seems to support this view. Also the parasites were at the extreme end of the small intestine and were immature.

Class CESTODA.

Order CYCLOPHYLLIDEA.

Super-Family DILEPIDOIDAE.

Family **DILEPIDIDAE.**

Sub-Family **DILEPIDINAE.**

Genus **DILEPIS** (Weinland).

Weinland 1858 fide Burt 1936.
Fuhrmann 1932 fide Burt 1936.
Burt 1936.

There are two species of this genus found in local shags which differ considerably from one another and from all other species of the genus *Dilepis.* These two species are described individually and then a comparison is drawn between each of them and the related species.

Dilepis maxima sp. nov.

Diagnosis of species.

Size.—13 cms. long x 1.21 mms. broad—864 segments.

Scolex.—350 μ broad with 4 suckers 114 μ in diameter.

Rostellum.—Is armed with a double crown of 20 hooks the larger being 153 μ the smaller 108 μ.

Genital aperture.—About 1-3rd of the distance down the left side.

Male genitalia—*cirrus* 0.1 mm. long armed at the base with two small spines 0.03 mm. long—*cirrus sac* 0.3 mm. long, *testes* normally 4 situated behind and laterally to the germarium in the medulla.

Female.—Vaginal pore ventral to cirrus—germarium and vitellarium median—ova 0.035 x 0.021 mm.

Genital ducts.—Dorsal to excretory canals.

Excretory canals.—The dorsal canals are narrower than the ventral canals, which are connected posteriorly by transverse commissures.

Host—M. melanoleucus—in the intestine.—A few.

General Description.

Several specimens of this worm were obtained from *M. melanoleucus* but not in any other species of shag. The worms measure about 130 mms. in length and have a maximum breadth of 1.21 mms. The scolex which is nearly square in surface view (see fig. 12) has a width of 0.43 mm. and a dorso ventral diameter of 0.35 mm. It bears 4 circular suckers 0.114 mm. in diameter. The rostellum is armed with a double crown of 20 hooks the anterior row being 108 μ long and the posterior 153 μ. (see fig. 13). The scolex as a whole is well marked off from the remainder of the strobila and is broader anteriorly (see fig. 11).—No specimen had the rostellum everted.

The neck region is fairly short (0.43 mm.) and passes without change of width (0.20 mm.) into the region showing strobilation which very gradually increases in width to the end of the strobila. The anterior segments measure 0.21 mm. x 0.07 mm. and these gradually increase in both directions especially in length until the sexually mature segments measure 0.56 mm. x 0.33 mm. The gravid proglottids measure 1.21 mm. x 0.57 mm. From the above it is evident that throughout the whole strobila the segments are rectangular and broader than long.

The genital apertures are unilateral, situated at about 1-3rd of the length of the proglottid from the anterior end.

Excretory canals.—There are two pairs of excretory canals—dorsal and ventral—both of which pass ventrally to the cirrus sac.

Genital Organs.

Male.—Normally 4 testes (0.07 mm. in diameter) lying behind and to the sides of the Female complex (see figs. 15-19).

In several segments 5 or 6 testes were found but none contained less than 4. The cirrus is armed with a pair of small spines at its base (0.03 mm. long) (see fig. 14).

The vas deferens which opens into the cirrus pouch is very coiled and is situated in the anterior end of the proglottid and extends beyond the middle line. The cirrus sac itself is very long (0.3 mm.) and contains the vesicula seminalis. The actual disposition of the organs can be seen in the figures (15-19). (The cirrus itself is 0.1 mm. long.)

Female.—The vagina opens into the genital atrium just ventral to the cirrus. The female genital complex is median, the bilobed germarium (each wing 0.03 mm. in diam.) lying anterior to the slightly lobed vitellarium (0.035 mm. in diam.) (see fig. 16). The receptaculum seminis is large and median—between the two lobes of the germarium. A duct from this enters the oviduct which then passes on to receive the vitelline duct and enter the shell gland which is small and inconspicuous. The uterus arising from this becomes bilobed and gradually expands laterally and downwards until it finally fills the whole segment. When first formed it is just a single lobe on either side. However it gradually becomes more and more lobed—the two halves uniting anteriorly. Finally the uterus breaks up into a number of egg capsules (see figs. 14-22).

(See note at end of description of D. *minima* (page 11).)

Dilepis minima sp. nov.

This is a very small form measuring 5.5 mm. and consisting of about 90 segments. I have not so far been able to work out the detailed anatomy of this worm, but the following description should serve for the identification of the species.

Diagnosis of Species.

Size.—About 5.5 mms. long x 0.2 mms. broad, about 90 segments.

Scolex.—0.31 mm. x 0.28 mm. bearing 4 suckers each 0.13 in diam.—rostellum 0.14 mm. in diam., armed with a double crown of 20 hooks—larger hooks 110 μ—smaller 100 μ.

Genital pores.—Unilateral, about middle of left side of proglottid.

Male Genitalia.—Cirrus 0.24 mm. long—armed with backwardly directed spines 5 μ long. Testes 3 in number one to each side of, and one posterior and dorsal to female complex.

Female Genitalia.—Median in position. Vagina posterior to cirrus.

Ova.—14 μ in diameter.

Host.—*P. varius, M. melanoleucus* & *P. ater*: Numerous.

General Description.

The worm measures up to 5.5 mm. in length and has a maximum width of 0.2 mm. There are 60-90 segments (see fig. 23). The scolex is large and sharply marked off from the remainder of the strobila which is segmented immediately behind the scolex, i.e., there is no neck. When the rostellum is everted the scolex measures 0.31 mm. in length x 0.28 diam. (See fig. 24.) It bears 4 circular unarmed suckers 0.13 mm. in diam. The globular rostellum 0.14 mm. in diam. bears 2 crowns of hooks about 20 in number approximately equal in size and alternating—upper row 0.11 mm. long—lower 0.10 mm. long (see fig. 25). The length of the attachment in both is 0.03 mm. The hooks are approximately 0.009 mm. wide at the base and they taper to a point.

The first formed segments measure 0.186 mm. wide x 0.01 mm. long, and as the segments become sexually mature they increase in length but not in width (0.186 mm. x 0.026 mm.) until the uterus begins to be formed when it reaches (0.2 x 0.043).

This relatively much greater increase in length than width becomes much more marked in the gravid segments (0.2 mm. x 0.2 mm). These segments separate off from one another to a certain extent so that they resemble a string of beads. The genital pores are unilateral and are situated in about the middle of the segments. The cirrus is very elongated (0.24 mm.) and beset with numerous small spines projecting posteriorly (0.005 mm. long) (see fig. 32).

Excretory canals.—There appears to be only one pair of longitudinal excretory vessels.

Male genital organs.—There are three testes (0.026 mm. x 0.014 mm.) lying one on each side of the Female complex and one median and posterior to this (see figs. 26 and 27). They gradually disappear as the uterus begins to develop (about segment 26). The vas deferens is coiled and opens into the cirrus pouch which extends to beyond the middle of the proglottid. The cirrus pouch contains the armed cirrus which when everted is as long or longer than the breadth of the proglottid.

Female genitalia.—The Female genitalia are median in position (see fig. 27). The germarium is bilobed (each lobe being about 0.007 mm. in

diam.), and the vitellarium (0.01 mm. in diam.) is situated between the two lobes and posteriorly to them. The uterus is developed as a bilobed structure which gradually increases in size, finally the halves uniting and filling the whole segment (see figs. 28-31). All the genital organs with the exception of the uterus and cirrus have disappeared in segment 39 and from this segment on to the end the uterus gradually matures. The eggs are about 0.014 mm. in diameter.

Note.—These two species (*D. maxima* and *D. minima*) show a superficial resemblance to worms of the Family *Hymenopelidae,* but they are definitely distinct from this group in an important feature—namely, they possess two rows of hooks on the rostellum instead of one which is characteristic of the *Hymenolepidae.* The possession of three or four testes seems to indicate a relationship with this family, but other species of *Dilepis* have been described which possess only three or four testes.

According to Burt only three species of *Dilepis* are known from *Pelecaniformes* and he describes a further species making the number up to four. A table will clarify the difference between the two new species and these four.

DILEPIS (WEINLAND).

——	D. kempi (Southwell).	D. scolecina (Rudolphi).	D. delachauxi (Fuhrmann).	D. lepidocolpos (Burt).	D. maxima (sp.nov.).	D. minima (sp.nov.).
Length	5cms. x 1mm.	...	....	20cms x 1·8mm.	13cms. x 1·21mm.	5·5mm. x 0·2mm
No. of proglottides	500	....	...	450	864	up to 90
Scolex	220μ x 400μ	500μ	..	700μ broad	350μ	310μ
Suckers ...	100μ	170μ	....	260μ	114μ	130μ
Rostellum	170μ	200μ	....	330μ	....	140μ
Hooks—Anterior	175μ	93μ 103μ	465μ	105μ	153μ	110μ
Posterior	135μ	63μ–64μ	282μ	84μ	108μ	100μ
Genital pores				left side	left side	left side
Male genital organs (Cirrus)	small and insignificant	190μ x 80μ	....	153μ x 34μ armed with spines 8·5μ long	armed with 2 small spines at base. (0·03mm. long)	240μ armed with spines 5μ long
Testes	3	numerous	..	4 in transverse row	4 (behind and to side of Female complex)	3 in transverse row
Female pore ...	in front of cirrus	posterior to cirrus	....	antero-ventral to cirrus, armed with spines	ventral to cirrus	ventral to cirrus
Germarium	median	...	poral	poral	median	median
Genital ducts				dorsal to excretory canals	dorsal to excretory canals	
Excretory canals	....	....	...	narrow dorsally and wide ventrally	narrow dorsally and wide ventrally	
Ova	....	...	....	10·5μ	35μ x 21μ	14μ
Fixation	....	scolex in a sac	....	scolex in a sac	scolex not in a sac	scolex not in a sac

Class ACANTHOCEPHALA.

Order PALAEACANTHOCEPHALA.

Family **POLYMORPHIDAE.**

Sub-Family **POLYMORPHINAE.**

Genus **CORYNOSOMA** (Lühe), 1911.

Corynosoma clavatus sp. nov.

This species corresponds to the definition of the genus *Corynosoma* as given by Meyer (1932), but differs from all the other known species of this genus in that the neck region is very long and when extruded (fig. 33) closely resembles the genus *Polymorphus.* It differs from this genus however in the shape of the cement glands, which are pear-shaped and not tubular.

Specific diagnosis.

Female 3.32 mms. long (neck everted).

Female 2.07 mms. long (neck retracted).

Male 1.4 mms. long (neck retracted).

(No specimen found with anterior body everted.)

Proboscis armed with 14 longitudinal rows of 10-11 hooks.

Neck partly armed. When the neck is everted in the female the position of the demarcation between the neck and the posterior body is 1.25 mms. from the anterior end. Testes (0.29 mm. x 19 mm.).

Cement glands 0.14 mm. x 0.13 mm.

Eggs 0.029 mm. x 0.17 mm.

Host.—P. varius, M. melanoleucus, P. ater.—Numerous.

General Description.

When the neck is everted the female is 3.32 mms. in length and the greatest depth is 0.7 mm. (see fig. 33). In this condition the form closely resembles Polymorphus. However when the neck is retracted, it is disc-shaped and measures 1.3 mm. in diameter (see fig. 34). The male is appreciably smaller than the female, being 1.4 mm. (neck retracted) x 0.6 mm. in the greatest depth. (Judging from the relative size of the female neck, the male would have a total length of about 2.5 mm.)

The neck and proboscis measures 1.25 mms. in length in the female. In both male and female the proboscis is 0.63 mm. long, and is armed with 14 longitudinal rows of 10-11 hooks which are largest in the middle and very small posteriorly (see fig. 35).

Relative sizes of the hooks:—

anterior (5-6)—0.04 x 0.014 mm.
middle (6-7)—0.074 x 0.029 mm.
posterior (7-11)—0.036 x 0.007 mm.

The proboscis is club-shaped, being:—

0.14 mm. in diam. anterior.
0.2 mm. in diam. middle.
0.16 mm. in diam. posterior.

The base of the neck (0.5 mm.) is armed with a few small spines 0.02 mm. long and these spines become larger (0.03 mm.) and more numerous around the constriction which is very distinct. From here they extend ventrally for a short distance.

The proboscis sheath is 0.86 mm. long x 0.19 mm. wide and the lemnisci are small and band-like.

Genitalia.

Male.—The testes are large and oval (0.29 mm. x 0.19 mm.), the right being slightly further anterior than the left. In the contracted condition of the neck the testes lie in the disc-like structure to either side of the proboscis. The cement glands are 6 in number and pear-shaped, measuring 0.14 mm. x 0.13 mm. The cement ducts are wide and unite to form a reservoir. The ejaculatory duct opens into the bursa whose walls are folded in the introverted condition (see figs. 36-38).

Female.—The eggs which are 0.03 mm. long x 0.014 mm. wide fill all the body space in the female. The genital pore is terminal and the vagina is very muscular.

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KEY TO LETTERING OF TEXT FIGURES.

a.g.—adhesive gland.

a.t.—anterior testis.

b.—bursa.

c.—cirrus.

c.d.—cement duct.

c.g.—cement gland.

c.r.—cement reservoir.

c.s.—cirrus sac.

cut.—cuticle.

d.—disc.

e.—egg.

e.c.d.—dorsal excretory canal.

e.c.v.—ventral excretory canal.

e.c.—excretory canal.

e.v.—excretory vesicle.

g.—germarium.

g.a.—genital atrium.

g.p.—genital pore.

h.f.—hold fast organ.

i.—intestine.

l.—lemnisci.

n.—nerve cord.

o.—ootype.

oes.—oesophagus.

o.d.—oviduct.

o.s.—oral sucker.

ph.—pharynx.

p.—proboscis.

p.r.—proboscis receptacle.

p.s.—pseudosucker.

p.t.—posterior testis.

r.—rostellum.

r.s.—receptaculum seminis.

s.—sucker.

s.g.—shell gland.

sp.—spine.

t.—testis.

u.—uterus.

v.—vagina.

v.d.—vas deferens.

ves. sem.—vesicula seminalis.

vit.—vitellarium.

vit. r.—vitelline reservoir.

v.s.—ventral sucker.

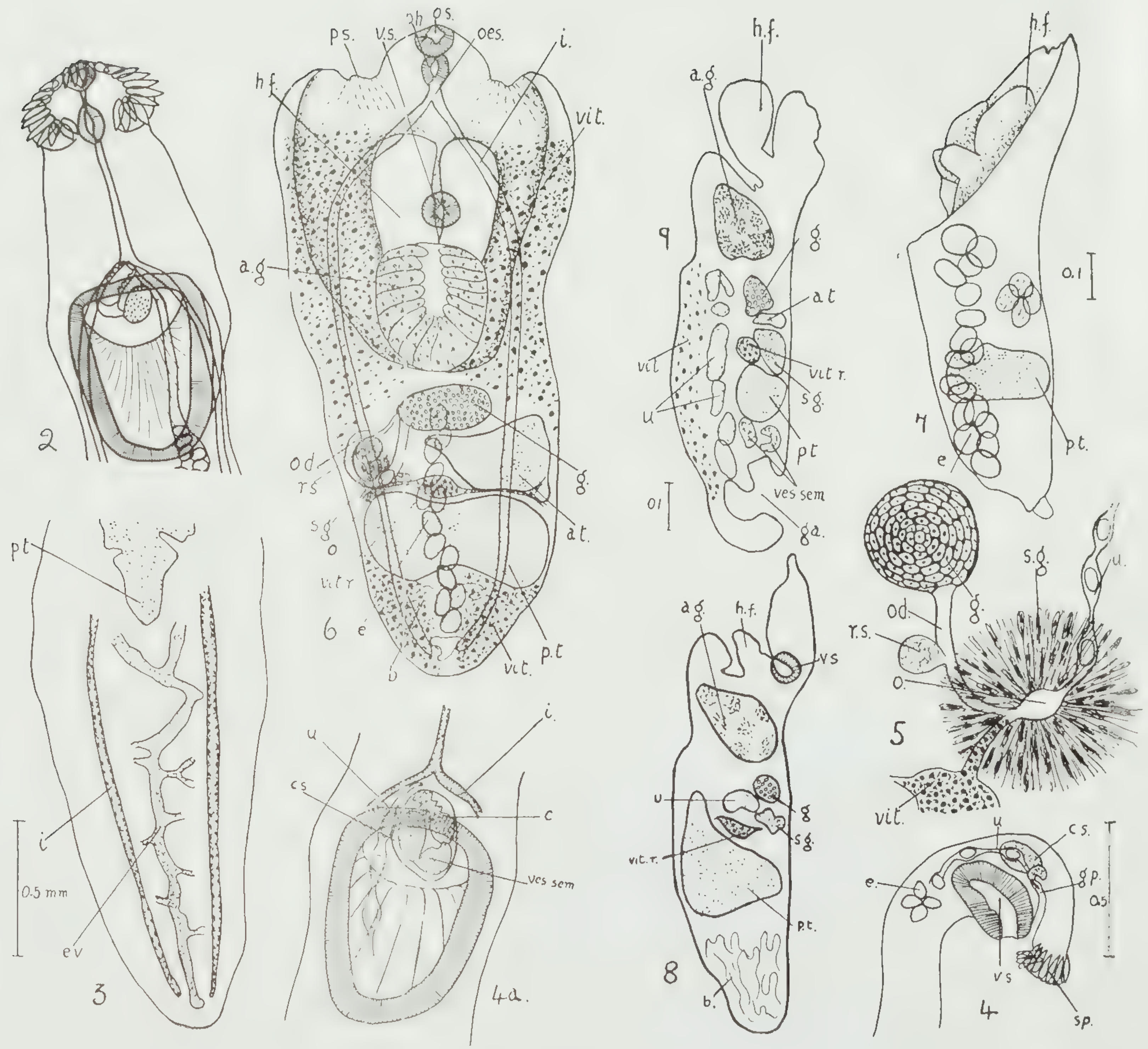
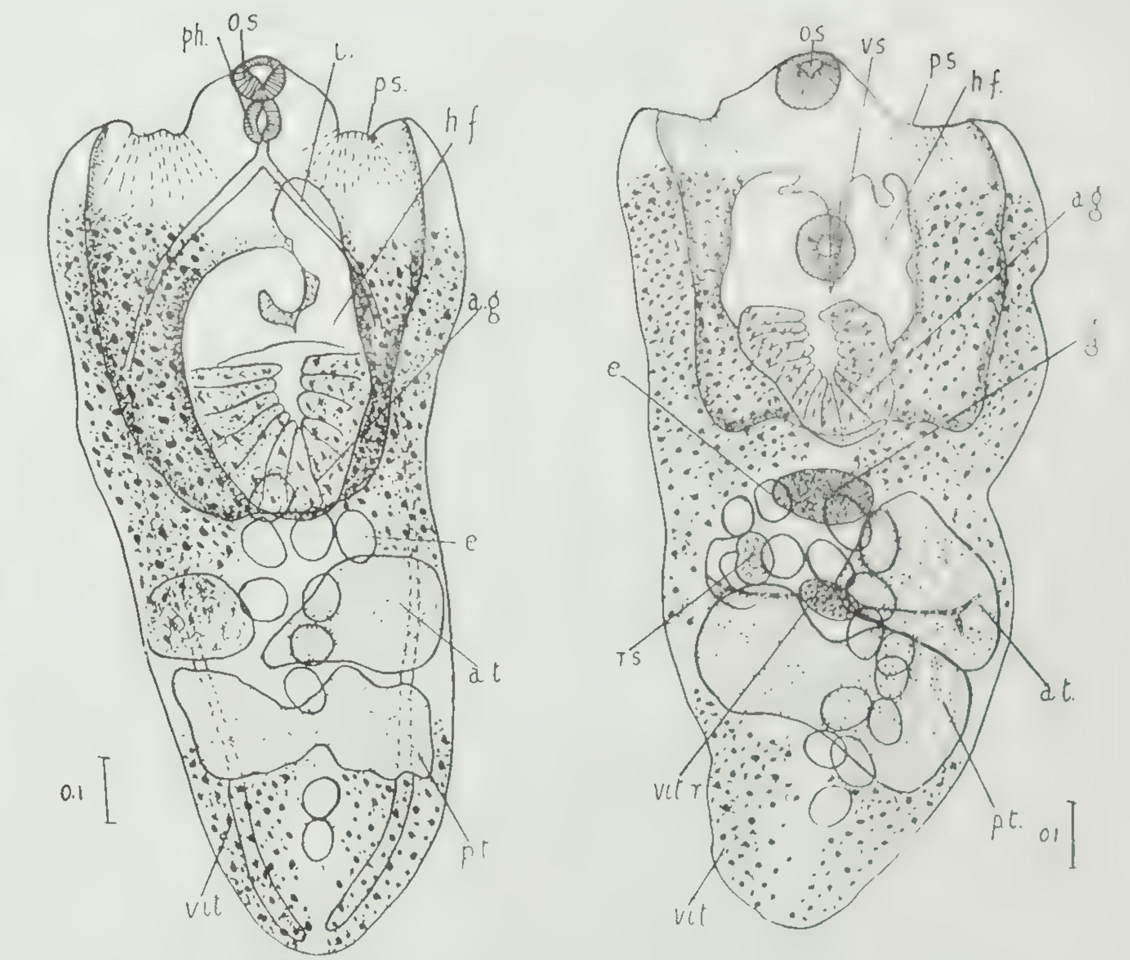


PLATE 1.—Figures 2-9.

Fig. 2. *Paryphostomum phalacrocoracis*—Head collar.
Fig. 3. *Paryphostomum phalacrocoracis*—Posterior region showing excretory vesicle.
Fig. 4. *Paryphostomum phalacrocoracis*—Side view showing cirrus sac.
Fig. 4a. *Paryphostomum phalacrocoracis*—Diagram of region round genital pore.
Fig. 5. *Paryphostomum phalacrocoracis*—Diagram of female complex.
Fig. 6. *Diplostomum granulosum*—Whole specimen reconstructed from several mounted specimens and from sections.
Fig. 7. *Diplostomum granulosum*—Side view showing hold fast organ and ventral uterus.
Fig. 8. *Diplostomum granulosum*—L.S. showing ventral sucker.
Fig. 9. *Diplostomum granulosum*—L.S. showing genital atrium and vesicula seminalis.
Figs. 5 and 6 diagramatic, others drawn with a camera lucida.



Diplostomum granulosum.

Two specimens from which figure 6 was drawn. Drawn with the aid of a camera lucida.

PLATE 2.—Figures 11-32.

Fig. 11. *Dilepis maxima*—Side view of scolex.

Fig. 12. *Dilepis maxima*—Face view of scolex.

Fig. 13. *Dilepis maxima*—Rostellar hooks.

Fig. 14. *Dilepis maxima*—Diagram of cirrus and cirrus sac.

Figs. 15-22. *Dilepis maxima*—Show development of reproductory organs in segment

Fig. 23. *Dilepis minima*—Whole specimen.

Fig. 24. *Dilepis minima*—Scolex with rostellum everted.

Fig. 25. *Dilepis minima*—Single hook.

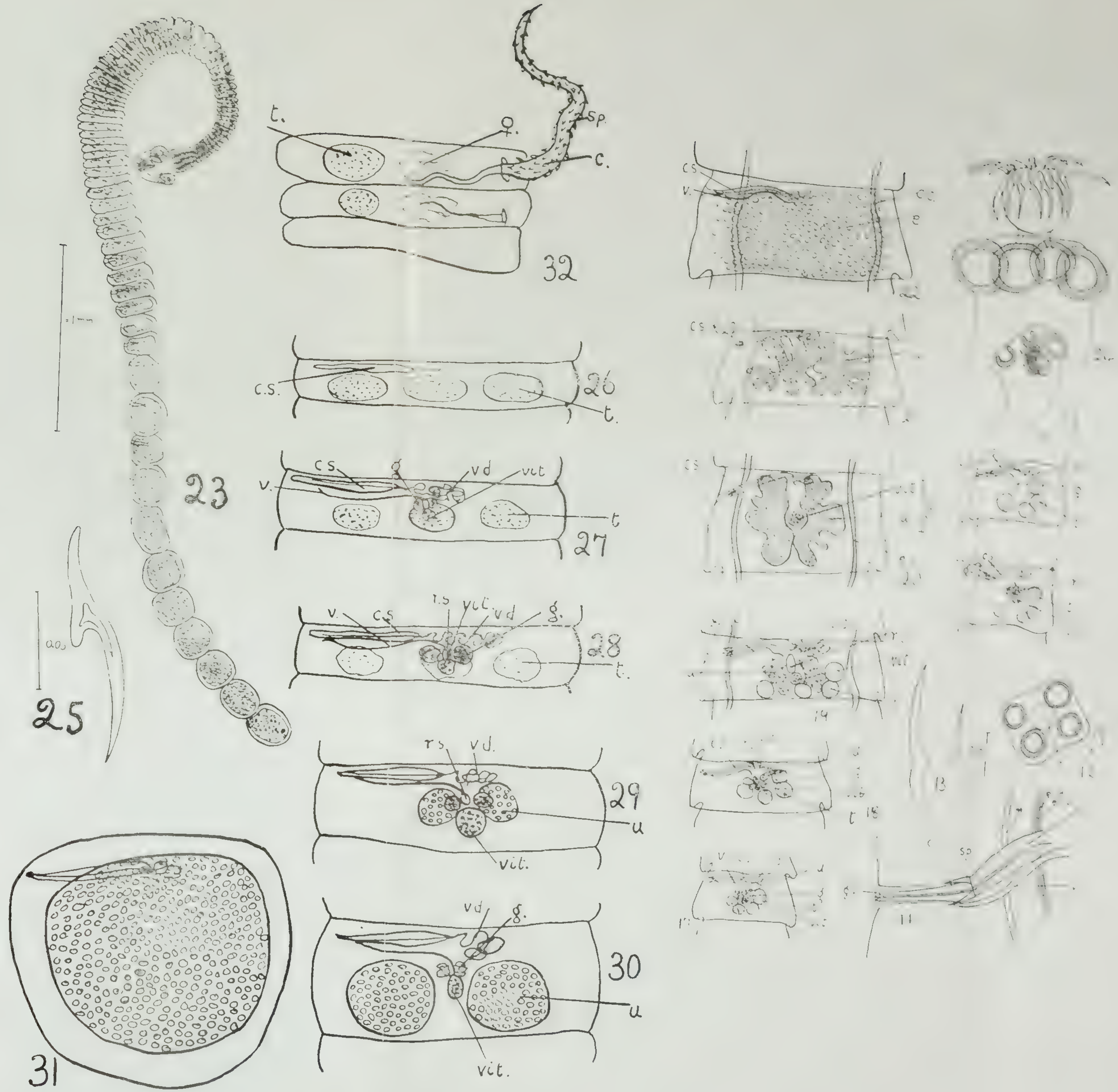
Figs. 26-31. *Dilepis minima*—Show development of the reproductory organs.

Figs. 32. *Dilepis minima*—Everted cirrus.

Fig. 14 is slightly diagramatic.

Figs. 26-31—Diagramatically drawn from several specimens and from sections.

All remainder camera lucida diagrams.



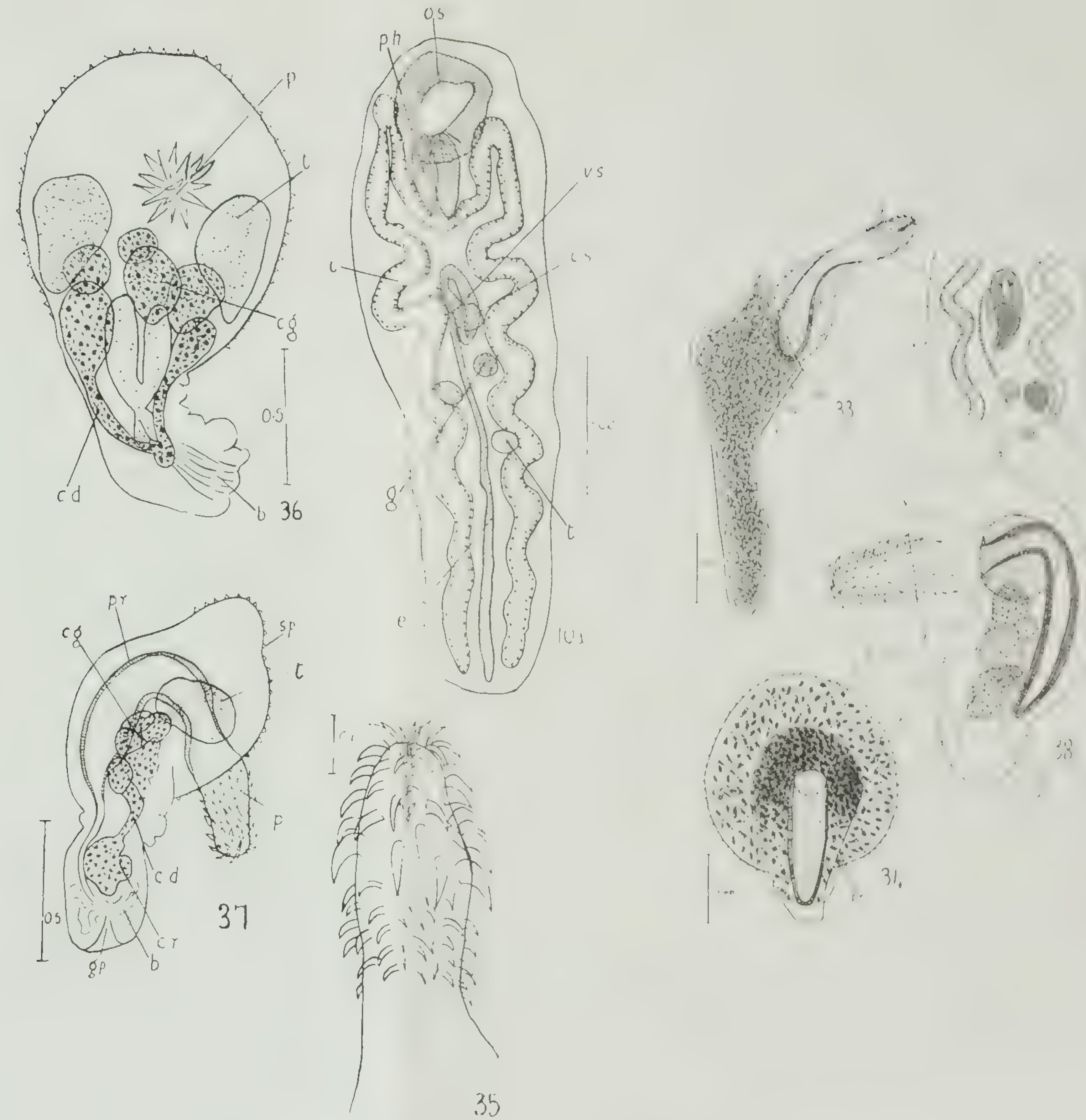


PLATE 3.—Figures 10a and b, 33-38.

Fig. 10a. *Steringophoridae*—Whole specimen.

Fig. 10b. *Steringophoridae*—Region of ventral sucker showing cirrus sac and sup posed uterus and shell gland.

Fig. 33. *Corynosoma clavatus*—Female specimen with anterior body expanded.

Fig. 34. *Corynosoma clavatus*—Dorsal view of female specimen with anterior body retracted to show disc-like expansion.

Fig. 35. *Corynosoma clavatus*—Proboscis enlarged.

Fig. 36. *Corynosoma clavatus*—Dorsal view of male specimen.

Fig. 37. *Corynosoma clavatus*—Side view of male specimen.

Fig. 38. *Corynosoma clavatus*—Side view of male specimen.

All camera lucida diagrams.

2.—THE ESSENTIAL OILS OF THE WESTERN AUSTRALIAN EUCALYPTS.

PART VI.

THE OIL OF *EUCALYPTUS CONCINNA*, MAIDEN ET BLAKELY.

By G. E. MARSHALL and E. M. WATSON.

Read 11th July, 1939; published 1st July, 1940.

E. concinna is described by J. H. Maiden (1). The material from which the species was described was obtained by the Elder Exploring Expedition of 1891-92 in the vicinity of Camp 49. This locality, which marked the only occurrence of *E. concinna* known to Maiden, is 155 miles due north of Rawlinna and about 185 miles east of Laverton. The species is now known to occur at least as far westwards as Mulline, about 30 miles roughly south-west of Menzies, and thence southwards beyond Southern Cross to Mount Holland, about 70 miles south of the eastern railway.

The species occurs both as a mallee and in the form of small slender trees. The leaves are fairly light, glossy green in colour and are narrow lanceolate in shape; the lamina is herbaceous and is freely dotted with oil glands; the venation, which is obscure, is pinnate, the lateral veins leaving the midrib at an angle of about 45°; the intramarginal vein is very close to the margin and is indented to meet the lateral veins. The bark is smooth and becomes rough on aging. The heart wood is pale brown in colour.

The material used in this investigation was obtained from mallees, and was collected, in August, 1938, about seven miles south of Laverton through the courtesy of Mr. R. A. Hobson and Mr. K. R. Miles of the Geological Survey. It was identified by Mr. G. R. W. Meadly, the acting Government Botanist.

The oil distilled fairly rapidly and was obtained in from 1.7 to 1.8 per cent. yield calculated on air-dried weight. It is pale yellow in colour and has a slightly irritant odour. Its physical constants are those of the typical cineol oils, and its solubility in alcohol shows a low proportion of hydrocarbons. The cineol content is nearly 65 per cent. and pinene is only present in small amount; free acids and esters are also present in only small proportion, but alcohols, the greater part of which is geraniol, make up somewhat more than 15 per cent. of the oil. Aldehydes are present in rather more than usual amount and are principally low boiling. Aromadendrene is present in relatively small amount and phellandrene is absent. Nearly 76 per cent. of the oil is distilled between 165° and 195° and this rectified oil complied with the requirements of the British Pharmacopoeia for medicinal eucalyptus oil.

EXPERIMENTAL.

The oil was obtained in from 1.7 to 1.8 per cent. yield and had the following physical constants at 20°:—Specific gravity 0.923; refractive index, 1.4650; specific rotation,—0.18°; soluble in 2 volumes of 70 per cent. alcohol. Its acid value was 1.2; its ester values were 7.5 (cold) and 8.0 (hot), corresponding respectively to 2.6 per cent. of geranyl acetate and 2.8 per cent. of total esters calculated as $C_{12}H_{20}O_2$. The ester values of the acetylated oil were 54.5 (cold) and 64.1 (hot), corresponding respectively to 12.9 per cent. of geraniol and 15.4 per cent. of total alcohols calculated

as $C_{10}H_{18}O$. The cineol content was 64.4 per cent., whilst aldehydes were present to the extent of 0.12 milligram mol. per gram of oil. The oil gave a bright yellow colour with ferric chloride and gave the usual colour reactions for aromadendrene.

The oil was redistilled at a pressure of 21 mms. and the fractions which were separated had the following properties:–

Fraction.	Boiling Range.	Amount.	Specific Gravity.	Refractive Index.	Specific Rotation.
		per cent.			
1	Up to 60°	4.2	0.893	1.460	+ 20.0°
2	60°—64°	8.3	0.900	1.461	+ 14.7°
3	64°—68°	41.7	0.911	1.461	+ 8.3°
4	68°—76°	27.4	0.923	1.461	— 2.1°
5	76°—100°	6.9	0.952	1.477	— 23.4°
6	100°—107°	4.6	0.972	1.493	— 29.3°

The formation of white insoluble material, which has been frequently noticed in these investigations, was again noted; the separation commenced at about 75° and increased slowly during the distillation. The small amount (0.39 per cent.) of this material formed was separated from the residue by addition of ether and filtration.

Fractions 1 and 2 were both very pale yellow in colour and had a slightly irritant odour. Fraction 1 contained appreciable amounts of free acid and of low-boiling aldehyde, whilst fraction 2 contained aldehyde and cineol. The two fractions were mixed, washed successively with concentrated resorcinol solution, aqueous alkali, and water, then dried and redistilled. From the fraction distilling between 155° and 160°, pinene nitrosochloride was isolated.

Fractions 3 and 4 were practically colourless and had a non-irritant, camphoraceous odour. The combined fractions made up 69 per cent. of the oil and, on mixing, had the following physical properties:—Specific gravity, 0.915; refractive index, 1.4610; specific rotation, +4.4°; soluble in 2.5 volumes of 70 per cent. alcohol. The cineol content of the mixture was 77 per cent., and the aldehyde content was 0.01 milligram molecule per gram, which is about one-tenth of the maximum aldehyde content permitted by the British Pharmacopoeia.

Fractions 5 and 6 were colourless and pleasant smelling. They had cold saponification values of 11.2 and 21.6 respectively, corresponding to 3.9 and 7.6 per cent. of geranyl acetate. The corresponding hot saponification values were 15.0 and 32.0 which are equivalent to 5.2 and 11.2 per cent. of the total esters calculated as $C_{12}H_{20}O_2$.

The residue slowly developed a purple colour when treated with ferric chloride.

The authors wish to express their thanks to Mr. G. R. W. Meadly, Mr. R. A. Hobson and Mr. K. R. Miles for their assistance.

REFERENCE.

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Perth Technical College.

3.—MARINE JURASSIC IN THE NORTH-WEST BASIN, WESTERN AUSTRALIA,

By Curt Teichert.

Read: 12th September, 1939; published: 28th August, 1940.

CONTENTS.

ABSTRACT.

The discovery of marine strata of Jurassic age in the North-West Basin is announced. They contain *Parachaetetes megalocytus* Pia, *Echinotis sinuata* sp. nov., and *Ostrea tholiformis* Etheridge. The strata are correlated with the marine Bajocian of the Geraldton District, 400 miles to the south of the new locality, and it is concluded that the Bajocian transgression in Western Australia may have had a much wider range than had been supposed. The discovery of Jurassic in the North West throws important light on the history of the North-West Artesian Basin and may also prove to be of economic interest.

INTRODUCTION.

Jurassic strata were once believed to have a wide distribution in Western Australia. On the latest available geological map of the State (Blatchford 1934) a continuous belt of strata of this age is indicated from Muchea, 30 miles north of Perth, in the south as far as the Fortescue River, about 900 miles up the coast in the north, and again from Wallal, 150 miles north of Port Hedland, to the southern shores of King Sound in the vicinity of Derby. Subsequently it was shown by Raggatt in 1936 that the country indicated as Jurassic in the North-West Basin between the Wooramel River and Onslow actually consisted of strata of Cretaceous age and the Jurassic was altogether eliminated from the map published by this author. Realizing that there was very little or no evidence of Jurassic strata in the greater part of the area formerly believed to be underlain or covered by strata of Jurassic age, Clarke in a recently published sketch map (1938, p. 37) showed the strata of known Jurassic age to be restricted to two areas, viz., a narrow strip of marine and continental deposits in the Geraldton District in the southern part of the State, and a small area of continental deposits in the vicinity of Derby at about lat. 17°. This sketch map is here reproduced, with slight alterations, as fig. 1.

Until recently, the strata of the Geraldton District were the only definitely established marine strata of Jurassic age in Western Australia, and at the same time in Australia in general. Spath (1939) determined the age of these strata as Middle Bajocian. During 1938 and 1939, however, evidence was accumulated proving the existence of strata of approximately the same age in the North-West Basin (see fig. 1).

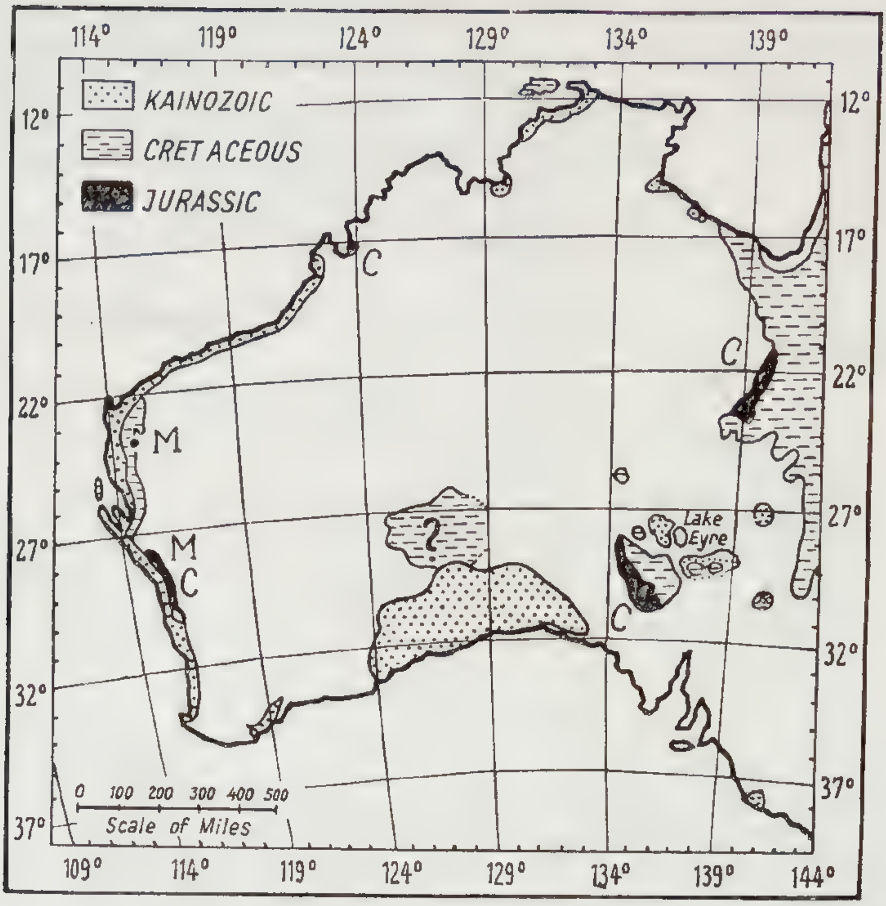


Fig. 1.—Distribution of Mesozoic and Kainozoic rocks in Middle and West Australia.

M = marine Bajocian, C = undivided continental Jurassic. The dot at 23°45 lat. marks the situation of map area fig. 2. (Adapted from E. de C. Clarke, 1938.)

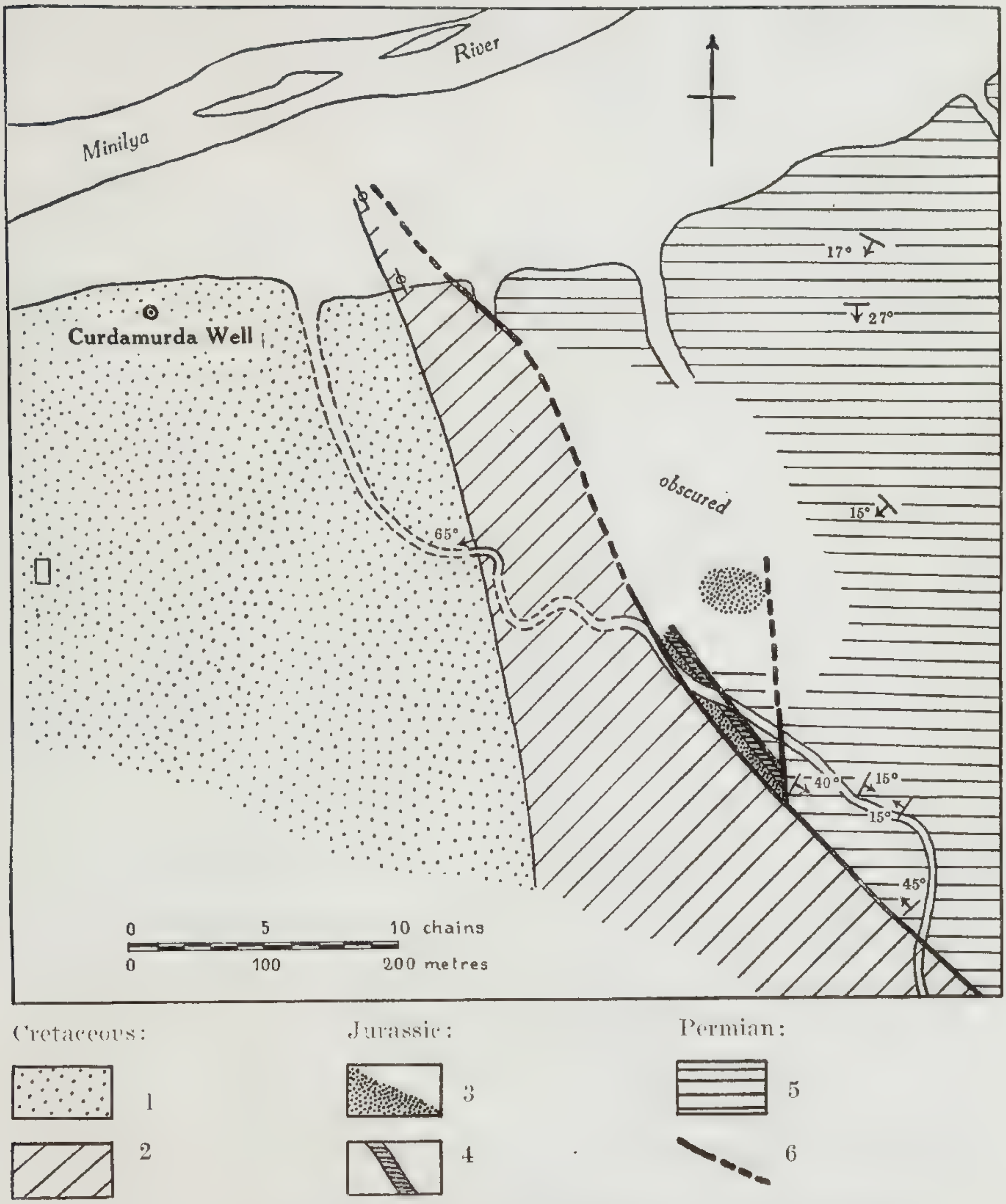
The discovery of fossils which later turned out to be of Jurassic age, was first made by Mr. H. Coley at a place about 30 chains (600 meters) southeast of Curdamurda Well on Wandagee Station, near the Minilya River. The writer visited the locality in May, 1938, being then under the impression that the strata in this place were part of the Permian series which is well developed in the immediate vicinity. Up to that time only a few specimens of calcareous algae had been secured from this locality which were sent to Professor Pia in Vienna who immediately stated his opinion (in a letter to the writer) that the algae belonged to a Jurassic genus. In May, 1939, the writer revisited the place on the Minilya River and succeeded in obtaining invertebrate fossils from these algal beds which show definite relationships to fossils of the marine Bajocian series of the Geraldton District.

In the following, a description of the locality and of the invertebrate fossils will be given, whereas the calcareous algae are being described in a separate paper by Professor Pia (1940).

DESCRIPTION OF THE LOCALITY.

The new locality is situated on Wandagee Station, on the south side of the Minilya River, 30 chains (600 metres) southeast of Curdamurda Well. On previous geological maps, up to 1933, the country here was indicated as consisting of "Permo-Carboniferous." The existence of Cretaceous strata

in the Wandagee district was first noted by L. Glauert who, in 1926 (p. 53) listed *Dimitobelus canhami* (Tate) from "Wandagee Station, Minilya River," and it was shown by Raggatt, in 1936, that the country formerly mapped as "Permo-Carboniferous" consisted partly of Cretaceous and partly of Permian strata. The newly discovered Jurassic outcrops along a narrow strip between the Cretaceous and the Permian.



1. Siltstone. 2. Greensand. 3. Hard sandstone. 4. Algal sandstone. 5. Wandagee beds. 6. Faults.

Fig. 2.—Geological map of area east and south-east of Curdamuda Well, Wandagee Station, Carnarvon District. (The situation of this area is indicated in fig. 1. For "Curdamurda Well" read "Curdamuda Well.")

Our knowledge of the Cretaceous stratigraphy in this part of Western Australia is entirely due to Raggatt who also proved that along the Minilya River the Cretaceous strata are separated by a major fault from the Permian Wandagee beds lying immediately east of them. In the vicinity of this fault (see fig. 2) the Cretaceous is represented by glauconitic sandstone,

partly in vertical position or even slightly overturned, partly with a steep westerly dip, which is overlain by siltstones and cherts. The dip seems to decrease westwards with increasing distance from the fault. Raggatt has shown this series of greensand, siltstones and cherts to be of Lower Cretaceous age and assigned it to the Winning series. No fossils were discovered in the greensand near the Minilya River, but several miles farther south, at Cundy Dam, near Wandagee Woolshed, greensand containing *Dimitobelus* is exposed in a similar stratigraphic position below the siltstones and cherts of the upper part of the Winning series. There can, thus, be little doubt that the greensand of the Minilya River forms the base of the Cretaceous series here (1).

North, as well as just south, of the Minilya River Permian strata (Wandagee beds) are found immediately east of the fault line separating the Cretaceous from the Permian. Usually, they are gypsiferous shales and thin-bedded sandstones, often strongly current-bedded and in places disturbed by minor faults. About a quarter of a mile south of the river these beds form a syncline with dips of both limbs up to 45°, running approximately in a N.E.-S.W. direction. This syncline is abruptly cut off by the main fault, running approximately at right angles to the direction of the syncline. It was here that the Jurassic strata were discovered.

As can be seen on fig. 2, the belt of Lower Cretaceous greensand is very narrow immediately south of the river where the attitude of the strata is vertical or even slightly overturned, and the strike is parallel to that of the fault. The maximum thickness exposed is here 130 feet, probably somewhat less. The greensand belt widens southward, partly owing to a slight decrease in dip of the strata, partly to an increase in thickness. A quarter of a mile south of the river it is 140 metres wide, corresponding to a thickness of the greensand of 410 feet as the strata are dipping west at 65°. Immediately to the east of the greensand there is here a narrow strip, about 13 feet wide on the surface, of unfossiliferous greenish weathering, grey hard sandstone, and to the east of this again a strip, likewise about 13 feet wide, of calcareous sandstone which yielded the Jurassic fossils mentioned above. Both sandstones are exposed over a length of about 470 feet along the edge of the greensand. At their southern end both belts are cut off by a fault striking 170°, and abut against Permian gypsiferous beds and sandstone. The conditions at the north end of the outcrop could not be ascertained, but to the east the Jurassic beds are undoubtedly separated by another strike fault from the gypsiferous Permian rocks.

The following fossils have been obtained from the algal sandstone:

Algae:

Parachaetetes megalocytus Pia.

Lamellibranchiata:

Echinotis sinuata sp. nov.

Ostrea tholiformis Etheridge jr.

(1) The name "Cardabia beds" was given by Glauert in 1926 to the strata with *Dimitobelus* and some of the specimens listed by this author as *Dimitobelus canhami* came undoubtedly from the vicinity of Cundy Dam. Later, Conditt, Rudd, and Raggatt named the entire Lower Cretaceous, including cherts and siltstones above the *Dimitobelus* beds, "Winning series," and Raggatt proposed the name "Cardabia series" for the Upper Cretaceous beds of the North-West Basin (see Raggatt, 1936). The greensand of the Minilya River district thus corresponds to the "Cardabia beds" of Glauert and to the lower part of the "Winning series" of Conditt, Rudd, and Raggatt.

The relationships of the algal beds to the hard sandstone and of both these strata to the Cretaceous greensand could not be established. The following possibilities exist:

(1) Faults separate the hard sandstone from the greensand as well as from the algal beds.

(2) Hard sandstone and algal beds form a conformable series separated from the greensand by a fault.

(3) Algal beds, hard sandstone and greensand are a conformable series.

The age of the unfossiliferous hard sandstone is uncertain, but it is very different in appearance from the Lower Cretaceous greensand or any other known Cretaceous beds here and elsewhere in Western Australia, and therefore probably forms part of the Jurassic sequence. On the other hand, the fault bounding the hard sandstone and algal sandstone belts on the south does not continue into the greensand. It seems, therefore, most reasonable to assume that the hard sandstone and the algal beds form a small fault block which has been squeezed up along the fault between the Cretaceous and the Permian.

Unfortunately, greensand, hard sandstone and algal beds can in this place only be observed in weathered surface outcrops and their true attitude could, therefore, not be determined. It is, however, most likely that they here are steeply dipping to the west and that the entire thickness of the Jurassic, including the hard sandstone, is less than 25 feet.

Slightly north of the north end of the belt of algal limestone is a small area covered with hard sandstone boulders which are similar to the rock of the hard sandstone belt. No surface outcrops are visible and it is thought that this occurrence gives evidence of another small fault block in which the hard sandstone series only is exposed.

CONCLUSIONS.

The marine Jurassic of the North-West Basin as described above, shows relationships to the Middle Bajocian strata of the Geraldton District as suggested by the occurrence of *Echinotis sinuata* and *Ostrea tholiformis* in both areas and it can, therefore, be assumed that the middle Jurassic transgression, so far only known from the country around Geraldton also affected at least part of the North-West Division of Western Australia. Its deposits are probably in most places either buried beneath the Cretaceous sediments or they were subjected to erosion before the Cretaceous sediments were deposited. Further search along the Cretaceous-Permian boundary of the district might, however, reveal additional limited outcrops of Jurassic strata. So far, the one here described is the only outcrop discovered, but the greater part of the North-West has never been examined in detail.

The discovery of Jurassic strata in the Minilya District sheds new light on the history of the North-West Artesian Basin. This Basin, as interpreted by the present writer (1939), is part of the Westralian Geosyncline which here contains 10,000 feet of Permo-Carboniferous and Cretaceo-Tertiary sediments. It is now evident that the time between the Permian and the Cretaceous has not been one of continuous emergence. It may be noted that marine Jurassic is also represented in the northern part of the Westralian Geosyncline, but these strata are of a different age and will be described elsewhere.

With regard to the bearing of the discovery of marine Jurassic in the North-West on economic questions, it may be pointed out that in the country west of the area occupied by the Permo-Carboniferous strata artesian water is obtained from strata below the Cretaceous which are now generally believed to be of Permian age. It must, however, now be regarded as possible that in certain places Jurassic strata may intervene between the Cretaceous and the Permian.

PALAEONTOLOGICAL DESCRIPTIONS.

GENUS **ECHINOTIS** MARWICK.

Genotype: *Avicula echinata* Smith.

The genus (1) was established by Marwick in 1936 for species formerly included in the genus *Pseudomonotis*, but differing from this genus mainly in their long and straight hinge-line. In addition to the genotype a number of mostly Middle Jurassic species will have to be included in this genus, among others *Avicula bramburiensis* Phillips, *Avicula ovalis* Phillips, *Monotis ornati* Quenstedt, *Monotis decussata* Münster, and *Monotis substriata* Münster. The distinguishing features of some of the German Dogger species have recently been discussed by Stoll (1934, p. 18).

Echinotis sinuata sp. nov.

Plate I; Fig. 1-10.

Holotype: No. 19211, Department of Geology, University of Western Australia.

Diagnosis: Outline subcircular, generally smooth primary and secondary ribs, shallow oblique sinus in posterior part of left valve.

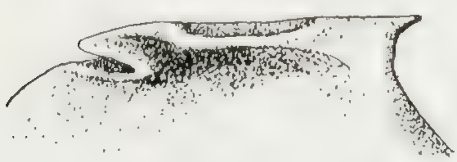


Fig. 3.—Hinge-line of right valve of *Echinotis sinuata* sp. nov. Railway cutting 19½ miles east of Geraldton. No. 19212. Department of Geology, University of Western Australia.

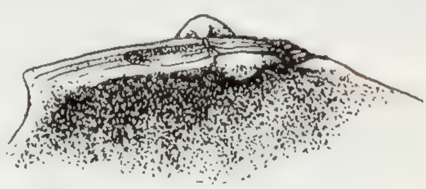


Fig. 4.—Hinge-line of left valve of *Echinotis sinuata* sp. nov. Railway cutting 19½ miles east of Geraldton. No. 19215. Department of Geology, University of Western Australia.

Description: Left valve subcircular, strongly convex, beak slightly projecting over the hinge-line; anterior ear very short, almost obsolete, posterior ear well developed, rectangular; ribbing very faint in the umbonal region, ribs gradually increasing in strength towards the ventral margin; in most specimens separation of ribs into primaries and secondaries well developed at a distance of about one-third the distance from the beak to the ventral margin; growth-lines clearly developed between the ribs, but only in a few specimens visible on the ribs, thus giving the ribs a knotted appearance; there is a slight swelling of the posterior part of the valve, separated from the rest of the valve by a shallow oblique sinus which starts to develop at

(1) Marwick used the spelling *Echinotus* in the heading of his description, but elsewhere throughout the article the spelling *Echinotis* is applied which is here accepted.

distance of about one-fourth the distance between the beak and the postero-ventral margin in adult shells; in different individuals sinus and swelling can be more or less pronounced, in some specimens both are very faint. Hinge (fig. 4) very similar to that of *Echinotis echinata* (see Pompeckj 1901, Marwick 1936); the triangular ligament pit is very shallow. The muscle scar is elliptical and situated slightly behind the centre of the valve. The largest ventral valve in the collection is 25 mm. long and 21 mm. high. (pl. 1, fig. 8).

Right valve somewhat irregular in shape, mostly subcircular, rather flat, but always with a distinct convexity of the umbonal region. Anterior ear very short and acute, posterior ear short and less acute; ribbing much weaker than on left valve, usually rather faint with no clear separation of primary and secondary ribs; also, distance between ribs greater than on left valve; concentric growth-rings mostly clearly visible, do not cross the ribs. Hinge (fig. 3) similar to that of *Echinotis echinata* (see Pompeckj 1901, Marwick 1936); ligament pit slightly longer than in that species. Muscle scar slightly smaller than in right valve.

Occurrence: In strata of Bajocian age with *Ostrea tholiformis, Trigonia moorei, Dorsetensia clarkei* and a rich fauna of other species in railway cutting on Geraldton-Mullewa line, nineteen and a half miles east of Geraldton, near Newmarracarra, and in strata with *Parachaetetes megalocytus* and *Ostrea tholiformis* in the locality described in the preceding section, viz., 30 chains (600 metres) southeast of Curdamuda Well, Minilya River, Wandagee Station, North-West Basin. The holotype has been selected from among the better preserved material from the first-named locality.

Remarks: Specimens very probably belonging to this species were first mentioned by Moore in 1870 (pp. 230, 232) who listed them as *Avicula echinata,* but apparently the species was not represented in the collection of Jurassic fossils studied by Etheridge (1910). It was again discussed by Whitehouse in 1926 who, however, only had one specimen at his disposal which he provisionally referred to *Pseudomonotis echinata.* Whitehouse had studied a large suite of individuals of this latter species from the Cornbrash of England and pointed out that the Western Australian specimen was "somewhat more circular in outline and has more pronounced division of the ribs into primaries and secondaries than the *average* English form; but the variation of the species in the Callovian covers such forms as the present."

The collections of the Department of Geology of the University of Western Australia contain a quantity of specimens which are evidently conspecific with the specimen studied by Whitehouse and, although I have not seen many specimens of the European *Echinotis echinata,* a careful comparison of published figures and descriptions of that species shows that the Australian form is not sufficiently similar to *Echinotis echinata* to be included in that species. Among the older descriptions of *Echinotis echinata* those by Sowerby (1821) and by Morris and Lycett (1853) are important. More recently, the species has been discussed and figured by Douglas and Arkell (1933), by Stoll (1934) and by Marwick (1936).

The following differences can be found between *Echinotis echinata* and *E. sinuata*:—

(1) *sinuata* attains a larger size than *echinata;*

(2) the ribs of *sinuata* are generally smooth, individuals with knotted ribs, like those of *echinata,* are very rare

(3) in *sinuata* separation of ribs into primaries and secondaries is the rule;

(4) posterior swelling and shallow sinus, characteristic of adult specimens of *sinuata,* are absent in *echinata.*

Since the range of variation of *Echinotis sinuata* is very considerable, certain specimens are more similar to *E. echinata* than the majority of average specimens.

The specimens from the Minilya River show less tendency towards the development of secondary ribs than the specimens from the Geraldton district. Also, though the few full-grown specimens obtained from the Minilya River are poorly preserved, they seem, as a rule to have a shallower posterior sinus than the Geraldton specimens.

Echinotis sinuata differs from the otherwise very similar *E. decussata* in the smaller number of ribs.

It may be noted that *E. sinuata* is not similar to the New Zealand form described by Trechmann (1923) as *Pseudomonotis* cf. *echinata.* As was also observed by Marwick (1936) that form is remarkably close to the typical European *Echinotis echinata.*

Genus **OSTREA** Linné.

Ostrea tholiformis Etheridge.

1910—*Ostrea tholiformis,* Etheridge, Oolit. Foss., p. 30, pl. 7, figs. 2-7.

This species has been well described by Etheridge from specimens from various localities in the Geraldton district. The specimen figured by Etheridge on pl. 7, fig. 3, now in the collection of the Geological Survey of Western Australia, is here selected as holotype.

The species is well represented in the collections from the railway cutting nineteen and a half miles east of Geraldton from which *Echinotis sinuata* has been described above. In the algal beds on the Minilya River, Wandagee Station, fragments of *Ostrea* shells are rather numerous, but only one almost complete specimen of an upper flat valve has been found which agrees well with specimens from the Geraldton district. Nothing can be added to Etheridge's description of the species.

ACKNOWLEDGMENTS.

The writer was accompanied in the field by Messrs. H. G. Higgins and E. P. Utting who supplied some of the data on which the map fig. 2 is based. Mr. G. Gordon Gooch very kindly provided numerous facilities, while the work on Wandagee Station was in progress, and Mr. Henry Coley first called the writer's attention to the occurrence of fossils in the locality described in this paper. Professor E. de C. Clarke kindly read and criticized the manuscript. The writer wishes to express his sincere appreciation of these services. Figs. 2, 3 and 4 and the accompanying plate were prepared by Mrs. Gertrude Teichert.

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EXPLANATION OF PLATE I.

Echinotis sinuata sp. nov. Figs. 1-8: Specimens from railway cutting nineteen and a half miles east of Geraldton; Figs. 9 and 10: Specimens from 20 chains south-east of Curdamuda Well, Minilya River, Wandagee Station, Carnarvon District.

Figs. 1-3.—Left, right and anterior views of holotype. No. 19211. The posterior ear is damaged.

Fig. 4.—Internal view of left valve of another specimen, showing posterior ear. No. 19213.

Fig. 5.—External view of left valve of another specimen, showing knotted appearance of ribs. No. 19214.

Figs. 6, 7.—External and internal views of right valve of another specimen, showing stronger development of secondary ribs than holotype. No. 19216.

Fig. 8.—Largest specimen in collection. No. 19217. Posterior ear damaged.

Fig. 9.—Left valve, showing well developed primary and secondary ribs. No. 19218.

Fig. 10.—Portion of larger left valve; secondary ribs weakly developed, posterior ear large. No. 19219.

All figures enlarged 1½ diameters. Specimens in the Department of Geology of the University of Western Australia.

PLATE I.

4.—A NEW FOSSIL ALGA (SOLENOPORACEA) FROM THE JURASSIC ROCKS OF WESTERN AUSTRALIA.

By Julius Pia,

Natural History Museum, Vienna.

Communicated by Curt Teichert.

Read: 12th September, 1939; published: 23rd August, 1940.

The material described in the present paper was collected in 1938 by Dr. C. Teichert of the University of Western Australia and submitted to me for examination. My best thanks are due to Dr. Teichert for entrusting to me his valuable specimens and giving me important information concerning the locality and the strata which had yielded the fossils. Prof. W. Soergel (The University, Freiburg in Breisgau) was so very kind as to lend me Deninger's type-specimens of *Parachaetetes ponticus*. I want also to thank the Royal Society of Western Australia, who kindly accepted my paper for publication.

The *locality* where the algae were collected is indicated by Dr. Teichert as follows: 600 metres southeast of Curdamurda Well, near Minilya River, Wandagee Station, Carnarvon District, Western Australia. This place is situated about 100 miles to the north of Carnarvon and about 700 miles north of Perth (see Teichert, 1940, fig. 2).

The age of the fossils was originally supposed to be Permian (Artinskian), as a very rich fauna belonging to this horizon had been collected within a short distance from the algal layers. When first examining the algae I was at once struck by their absolutely Jurassic general habit and I expressed some doubts concerning their Permian age. In 1939 Dr. Teichert made a closer examination of the locality and to my great comfort he found the algae to be of Mesozoic age. He expresses himself as follows (condensed from a letter written in the field): "When coming across this country last year I could not spend more than half an hour at the locality. It is situated on the strike continuation of Permian strata, which I had seen a few hundred meters to the north. Several meters to the south of the algal locality rocks of undoubtedly Permian age are again found *in situ*. However, we discovered an important fault, which brings Permian rocks into contact with the algal beds. The tectonic structure along this fault is rather complicated. Several smaller cross-faults seem to be present. The algal layers are only exposed in a very narrow zone about 200 metres long. They contain *Ostrea* and *Pseudomonotis*. Their fauna and flora as well as their lithological character is strange. No similar rocks have so far been observed in Western Australia. A *Pseudomonotis* resembling the one from this place has been found in the Middle Jurassic near Geraldton (nearly 400 miles to the south)."

By relating this little story I do not intend to imply that Solenoporaceae are of great value as age-indicators, for in fact they are not; nor that I think that the general habit of fossil organisms is of great chronological value. I believe that only really identical species should be used in correlating strata; thus, although *Parachaetetes asvanatii* of India is most nearly related to *Par. tornquisti*, yet the first is from Danian, the second from Middle Jurassic strata (Rama Rao & Pia, 1936, p. 34; Pia 1936, p. 19).

Despite all these qualifications it is, however, a fact, that by good luck the first suspicion concerning the occurrence of Jurassic strata on the Minilya River was derived from the examination of a few fossil algae.

The species under examination is a new one, but even if it had already been found in another place it would hardly enable us exactly to fix the age of the rocks containing it. Solenoporaceae have often a wide range in time. *Pseudochaetetes jurassicus* is found from the Middle Liassic to the uppermost Jurassic (Pia 1939). It is well known, that many of the living calcareous algae in the seas surrounding Australia are closely related to species from the older (Nummulitic) strata of Europe (cf. Pia 1936, p. 19). The same may have been true during former geological periods. So far only one species of Solenoporaceae has been found in the Lower Cretaceous. The Upper Jurassic flora is a rich one. Under these circumstances it would certainly be rash to argue, that a species known from Jurassic strata will never be discovered in Cretaceous ones. The exact age of our specimens, however, has been determined by finds of lamellibranchs from the same beds (*Echinotis sinuata* and *Ostrea tholiformis*) which are also found in strata of Middle Bajocian age in the Geraldton District.

The *material* under examination consists of three specimens: a beautiful big thallus, showing very well the general structure on two weathered surfaces, and two small nodules obviously much reduced by weathering.

The thallus is composed of stout radial lobes and branches separated by narrow fissures (Figs. 1, 2). The basis is not preserved. When complete the alga probably had a more or less hemispherical shape. The diameter can hardly have been less than six inches. The thallus is perforated by numerous tubes measuring several millimeters in diameter and filled with a sandy sediment (Figs. 1, 3.). Obviously they are the work of boring bivalves, so often found in recent and Tertiary Melobesieae.

On the weathered surface wavy concentric layers are clearly shown (Figs. 1, 2). They are convex upward in each branch.

Thin sections examined with the help of a hand lens show elongated radial *cells* and transverse *dark streaks* or bands (Fig. 3). The cell-walls consist of subcrystalline calcite. The interior of the cells is filled with clear, crystalline calcite. They are much longer than broad, arranged in distinct transverse layers. As a rule they are more or less curved, especially towards their lower end, where they are sometimes distorted in a remarkable way (Fig. 8). Generally no cross-walls can be detected between the successive dark streaks. Exceptions from this rule may occur, but they are difficult to ascertain owing to the irregular form of the cells, which makes it impossible to obtain a great number of exactly longitudinal sections.

The length of the cells is therefore equal to the distance between the dark streaks, which varies very much. Its average may be about 1.6 mm. The thickness of the cells shows also a marked variability (Fig. 6). I found the diameter of the cells to be 0.12—0.25 mm. (including half of the thickness of the cell walls on both sides). In cross-sections they are of an irregularly polygonal shape.

Dark bands are often mentioned in the descriptions of recent or fossil Corallinaceae and of Solenoporaceae. It seems probable that essentially different structures are included under the same name. In our alga the nature of the streaks is fairly obvious. As shown especially in tangential sections (Figs. 6 and 7) they correspond to a considerable thickening of the longitudinal cell-walls. The skeleton is more easily dissolved by percolating water,

than the crystalline calcite filling its cavities. That is the reason why the streaks appear as tiny furrows on the weathered surface (Fig. 1). The thickening of the cell-walls always occurs in the distal part of the cells. It increases gradually in a distal direction and then stops abruptly at the outer surface of the cell-layer.

One may at first question whether the cell-layers are separated by real transverse cell-walls or by the dark bands only. In some places, however (Fig. 8, upper streak), the cross-walls detach themselves from the streak. They become also visible when the streak is little developed. We have probably to admit that they are normally present, though seldom distinctly seen. They are really missing in a few places, but this may be due to dissolution or imperfect calcification.

The thickening of the cell-walls creating the appearance of the dark bands may be due to a secondary deposition of calcium carbonate, which occurred while the cell-layer formed the surface of the thallus and had to do most of the assimilation.

In one place the cross-walls showed a special microscopic structure, which in longitudinal section gives the aspect of a comb (Fig. 4). An exterior layer of the wall is homogenous and continues over many cells like a cuticula. The inner layer is crossed by very numerous dark lines, distant about 0.016 mm. This appearance is probably brought about by the presence of numerous pores ending in the wall without piercing the outer part of it. Such a structure looks very serviceable for the emission and absorption of gases, but if it is a normal one, it would be hard to explain why it was only found in one place, showing otherwise no exceptional state of preservation. Possibly it existed only in cross-walls which formed the surface of the thallus during a longer suspension of growth.

One of the most interesting features of the alga described in this paper is the occurrence of certain taller, sacciform or more irregular cells. Some of them are isolated, others are arranged in rosette-like groups (Fig. 5). They are always found close to a dark streak, but—peculiarly enough—not always on the same side of it. Most of them lie immediately above it, some below it. The wall lining them agrees in every respect with the ordinary cell-walls. Probably these taller cells are some sort of primitive sporangia.

In determining the *generic position* of our alga, we may for the present disregard the sporangia. Probably it will prove necessary later on to erect special genera and even families for the Solenoporaceae with peculiar types of sporangia. I should, however, like to make more observations before doing so. Under this assumption the alga, having well developed transverse cell-layers, clearly belongs to *Parachaetetes*, as defined by the author (Pia 1937 & 1939).

As far as I know, there exists only one related species showing a really close similarity with the alga from Western Australia. I gave recently a fairly complete list of the species of *Parachaetetes* (Pia 1939). Most of them are easily distinguished from the alga under examination by the much smaller size of their cells. Only *Parachaetetes ponticus* (Deninger 1906) has a similar tissue. Its cells are about 3 mm. long and 0.2 mm. broad. The description given by Deninger is very short and the drawings look somewhat schematic. It seemed possible that the Australian alga belongs to Deninger's species. Through the kindness of Prof. W. Soergel I was able

to compare it directly with Deninger's original slides. I am now convinced that the two species are to be kept apart. The chief differences between them are:

The whole structure of *Parachaetetes ponticus* is much more regular. The cells are straight, not bent. In cross-section they are all practically of the same diameter. In longitudinal section they are noticeably longer than in the alga from Western Australia.

The cross walls are ill defined, often interrupted. No dark streaks are developed.

I was not able to detect sporangia in the three slides I had at my disposal. This may, however, just be a matter of chance.

A star-shaped body brought about by the fusion of 6 cells, which is seen in a cross-section, is of doubtful significance. Probably it is only a casual structure.

I have not seen the specimen of *Parachaetetes ponticus,* from which the sections were cut. According to Deninger's description it can not be very different from the Australian alga. One of the slides from the Crimea shows a circular perforation filled with calcite and probably due to some boring animal.

From this comparison the following points seem to be fairly evident:

The Australian alga does not belong to the species *Parachaetetes ponticus* (Deninger) from the Oxfordian of the Crimea, although it shows a marked similarity to it. How closely the two algae are related cannot be decided, unless we can get a more satisfactory knowledge of the sporangia of both species.

The alga described in this paper is therefore a new species. I propose to give it the name *Parachaetetes megalocytus* sp. nov.

Definition: Diameter of thallus about ½ foot. Several stout branches are arranged to form a hemispherical body. Cells in well defined transverse layers, about 1.6 mm. long, about 0.18 mm. thick, much distorted in the proximal part, polygonal in transverse section. Longitudinal walls thickened in the distal part of the cells, thus giving the appearance of dark bands in slides and of concentric furrows on weathered surfaces.

By these dark streaks and by the irregular, less elongated shape of the cells *Parachaetetes megalocytus* is distinguished from *Parach. ponticus* (Deninger).

Type: The big specimen (Fig. 1 and 2) in the Department of Geology, University of Western Australia (No. 19220), with 3 slides. Additional material in the same institute and in the Geological Department, Natural History Museum, Vienna.

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EXPLANATION OF PLATES.

All figures **Parachaetetes megalocytus** sp. nov. from Minilya River, Carnarvon District, Western Australia. Specimens in the Department of Geology of the University of Western Australia.

Plate I.

Fig. 1.—Weathered surface of thallus, natural size. No. 19220.
Fig. 2.—Same specimen from opposite side. Natural size.

PLATE I.

Fig. 1.

Fig. 2.

Pia photo. Natural size.

Plate II.

Fig. 3.—Longitudinal section, showing cell-layers, dark bands, perforations by boring animals. × 5.6. No. 40935.

Fig. 4.—Cross-section of transverse cell-wall, showing tubular structure. × 150. No. 40936.

Fig. 5.—Transverse section, showing group of big cells (sporangia?). × 26. No. 40934.

PLATE II

Fig. 2. [illegible]

Fig. 1. [illegible]

Fig. 3. [illegible]

Pia photo.

Plate III.

Figs. 6 & 7.—Transverse sections, showing different size of cells and thickening of cell-walls (dark streaks). × 26. No. 40934.

Fig. 8.—Longitudinal section, showing distorted shape of cells, dark streaks, and cross-walls. × 26. No. 40935.

PLATE III.

Fig. 6

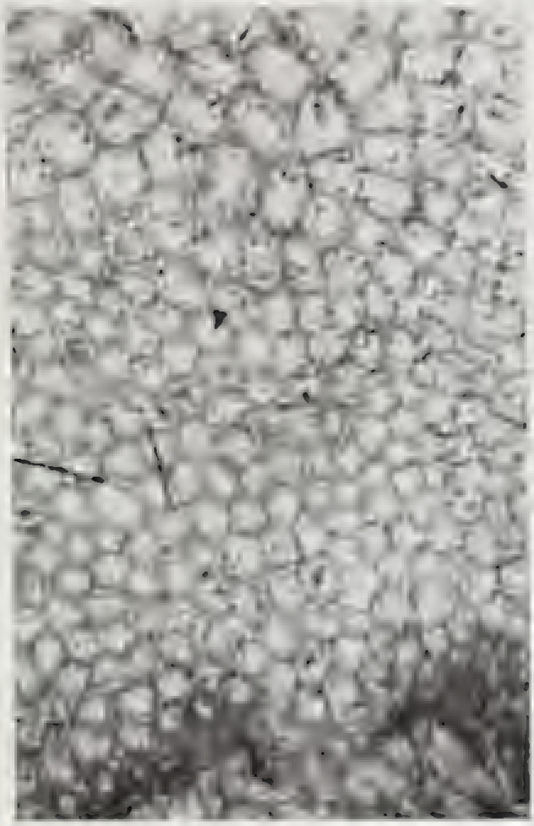

Fig. 7

Fig. 8

Pia photo.

5.—ON UPPER CRETACEOUS (MAESTRICHTIAN) AMMONOIDEA FROM WESTERN AUSTRALIA.

By L. F. Spath, F.R.S.

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The occurrence of late Cretaceous ammonites (referred to the Upper Senonian or Campanian) in the northwestern part of Western Australia (Cardabia Range) has only recently been recorded by Dr. H. G. Raggatt (1), and the determinations of the ammonites (by so competent an authority as Dr. F. W. Whitehouse of the University of Brisbane), suggested the presence of a fauna of considerable importance. I was very interested therefore to hear from Dr. C. Teichert of the University of Western Australia that he had made collections of ammonites from the same beds in 1938 and I gladly accepted his kind offer to have the fauna sent to me for study. For since I (2) first discussed comparable ammonites from Africa and their allies of the Ariyalur and Valudayur Beds of India, our knowledge of the late Cretaceous successions has been greatly extended. I was also anxious to see whether the recent great multiplication of ammonite zones in the higher Cretaceous of Japan modified our views of the successions in India, Australia and elsewhere.

There are 43 ammonoids in the collection before me and they came (in about equal numbers) from the west (locality B) and south-west (locality A) sides of Remarkable Hill, Cardabia Station. The map attached to Dr. Raggatt's account gives the position of this hill as about 85 miles due south of North West Cape, and from his geological data it may be seen that the ammonites occur (with coprolites and many foraminifera (3)) in a five-feet band of glauconitic sand or sandstone. This bed is overlain by sandy, white to yellow, polyzoan limestones, 85 feet in thickness, which have yielded *Ostrea vesicularis* and other fossils, dated by Dr. Whitehouse as Campanian; and the ammonite bed is underlain by *Inoceramus* Marls that contain a fauna said to be similar to that of the Gingin Chalk. The age of the latter is approximately indicated by the presence of *Uintacrinus* and *Marsupites* (Santonian and Campanian), but the ammonites known from that deposit (4) are not suitable for exact dating. While the age of the ammonite bed was thus roughly determined it seemed that the succession was too incomplete to help

(1) Geology of North-West Basin, Western Australia, etc. *Jour. Roy. Soc. N.S. Wales*, vol. lxx., pt. 1, 1936, pp. 160-161.

(2) On Cretaceous Cephalopoda from Zululand. *Ann. S. Afr. Mus.*, vol. xii., pt. 7, No. 16 (May, 1921): On Upper Cretaceous Ammonoidea from Pondoland. *Ann. Durban Mus.*, vol. iii., pt. 2 (August, 1921): The Senonian Ammonite Fauna of Pondoland. *Trans. Roy. Soc. S. Afr.*, vol. x., pt. 3 (1922).

(3) See Irene Crespin: Upper Cretaceous Foraminifera from the North-West Basin, W. Australia. *Journ. of Palaeont.*, vol. xii., No. 4, 1938, p. 391.

(4) Spath: Note on two Ammonites from the Gingin Chalk. *Jour. Roy. Soc. West. Australia*, vol. xii., 1926, pp. 53-5. There is another ammonite from the Gingin Chalk in the British Museum (Nat. Hist., Geol. Soc. Coll. No. 226) marked "near foot of Mt. Albert" (the specimen referred to in my paper on Jurassic Ammonites from Western Australia). It is crushed and very imperfect, but apparently it is also a *Pachydiscus* (? *Eupachydiscus*) like those previously discussed.

in the elucidation of the problems to which I directed attention in 1921 (1), namely the contemporaneity or otherwise of the diverse elements included in the Campanian and Maestrichtian. It will be necessary to discuss the probable sequence of the various Campanian-Maestrichtian horizons after the ammonoids have been considered in detail.

Genus **PARAPHYLLOCERAS**, Shimizu, 1935.

One example, still septate at 83 mm. diameter, and therefore representing the inner whorls of a large individual, is compared to *P. nera* (Forbes), the holotype of which is only 20 mm. in diameter. The Australian specimen is an internal cast, without trace of ornamentation, except rather closely spaced, sigmoidal folds, as in *P. surya* (Forbes). The latter has rather coarser ribbing than *P. nera* in the young, and it is less flattened laterally; but later the two species become very similar, except in the spacing of the costation. One of the syntypes of *P. surya,* in fact, at 72 mm. diameter (with body-chamber) may equally well be attached to *P. nera,* being more finely ribbed than the large example figured by Kossmat (2), but having an equal whorl-thickness (28%). Marshall (3) stated that the folds disappeared more quickly in his New Zealand form (= *P. marshalli,* Shimizu) than in *P. surya,* but in the Australian example before me, as well as in the syntype already mentioned, the folds (with or without pseudo-constrictions on the inner whorl-side in the young) persist, just as they do in *P. surya.* Since the genus *Paraphylloceras,* Shimizu (4) was proposed for the group of *P. surya* (Forbes) the closely allied *P. nera* must also be referred to that genus.

Genus **PHYLLOPACHYCERAS**, Spath, 1925.

There are two examples of *Phyllopachyceras forbesianum* (d'Orbigny) in the emended interpretation of Kossmat (5). Since this species, already recognised by Dr. Whitehouse, was referred to by him as *P.* cf. *forbesianum* he may have doubted its identity with the Valudayur form. I have before me, however, Forbes's original (B.M. No. R. 10476, Geol. Soc. Coll.) and topotypes from the Kaye and Cunliffe Collections, and there seems to be no difference either in suture-line or in dimensions; but while the beautifully preserved Valudayur specimens show the delicate ornamentation, the Australian examples are smooth, internal casts. In spite of Marshall's (6) remarks, the whorl-section is much more like that figured by Kossmat (7) than his own, misleading diagram. The suture-line, also, was incorrectly figured by the former author, and his identification of the New Zealand

(1) *Loc. cit.* (*Ann. Durban Mus.*), 1921, pp. 54-55.

(2) Untersuchungen über die südindische Kreideformation. Pt. i. *Beitr. Pal. Geol. Österr.-Ung.*, vol. ix., 1895, pl. xvi., fig. 1.

(3) *Op. cit.* (1926), p. 134, pl. 26, figs. 1-2. (The whorl-section is very misleading if the form is correctly referred to *P. nera*).

(4) See Spath: Problems of Ammonite Nomenclature VII. The genera *Paraphylloceras* and *Neophylloceras*, Shimizu. *Geol. Mag.*, 1939.

(5) Untersuchungen über die südinische Kreideformation Pt. iii. *Beitr. Pal. Geol. Österr.-Ung.*, vol. xi., 1898, p. 124.

(6) The Upper Cretaceous Ammonites of New Zealand. *Trans. N.Z. Inst.*, vol. 56, 1926, p. 136, pl. 19, fig. 6, pl. 27, figs. 3-4.

(7) *Op. cit.*, pt. 1, *Beitr. Pal. Geol. Österr.-Ung.*, vol. ix., 1895, pl. xv., fig. 1. (This form was later renamed *P. whiteavesi*, Kossmat).

form with Forbes' species may not be reliable; but Dr. Marshall was right in saying that there were twelve (external) saddles. These are followed by eight internal (dorsal) saddles, so that there are altogether eighty elements in the suture-line. It should be added that I agree with Gignoux (1) in deriving *P. forbesianum* from *P. infundibulum* and *P. rouyanum* (d'Orbigny) and therefore include it in *Phyllopachyceras*, Spath (1927) (2). According to Shimizu (3) *P. forbesianum* (of Santonian and Lower Campanian age) is succeeded by *P. ezoense* (Yokoyama), but I believe the two to be the same rather long-ranged species, or at least I can see no difference between the Japanese and Indian examples before me.

Genus **PSEUDOPHYLLITES**, Kossmat.

A septate fragment of a *Pseudophyllites* seems to have a slower rate of increase in whorl-height and thickness than the well-known Valudayur species *P. indra* (Forbes) (4). The height is 32 and 47 mm., respectively, at the two ends, the thickness 29 and 44 mm. The length along the siphonal line is just under 100 mm. and in the holotype of *P. indra* a corresponding change in dimensions appears to take place in a length of only about 80 mm. Combined with this apparent slower rate of increase in size there is a slightly less high umbilical slope, but it is difficult to tell whether these differences (in a single fragment) are of significance. The suture-line shows good agreement with that of *P. indra,* and I may mention that Whitehouse already referred a West Australian ammonite to that species.

Genus **HAUERICERAS**, Grossouvre.

A fragmentary example of an unkeeled *Hauericeras* (Plate II., Fig. 3), consisting of portions of two septate whorls, shows constrictions which are almost straight and only slightly projected peripherally as in Kossmat's (5) figure of *H. gardeni* (Baily). At a diameter of about 45mm. (reconstructed) the proportions were approximately .34-, .24-, .36, indicating a greater whorl-thickness than in *H. gardeni* which also has a less regularly oval section. The internal cast shows a siphonal groove, not deep, but very clearly marked, and it is possible that this corresponded with a keel on the test, but there is also no trace of a keel on the next inner whorl. The suture-line is that of a typical *Hauericeras.*

Stoliczka (6), who examined Forbes's original (figured) example of *Amm. durga* (B.M. No. R. 10467*a, b,* Geol. Soc. Coll.), thought that it was merely the young of *H. rembda* (Forbes), before the keel appeared; and I have previously (7) followed Stoliczka in identifying the two species. But the Australian example shows that there is such a species as *H. durga,* especially if Forbes's smaller second (unfigured) specimen be taken to re-

(1) Les Phylloceratidés du Paléocrétacé. *Mém. Carte géol. dét. France* (1920) 1921, p. 100.

(2) Sur quelques espèces du Gault, nommées par P. Reynès. *Ann. Mus. Hist. nat. Marseille,* vol. XX., 1925, p. 101.

(3) The Upper Cretaceous Cephalopods of Japan. I. *Jour. Shanghai Sci. Inst.,* sect. II., vol. 1, 1935, pp. 200, 201.

(4) See Kossmat, *op. cit.,* pt. i. (1895), p. 137, pl. xvi., fig. 9.

(5) *Ibid.,* pt. iii. (1898), pl. XVIII., fig. 7a.

(6) The Fossil Cephalopoda of the Cretaceous Rocks of S. India. *Pal. Indica,* ser. 3, pt. 2, 1864, p. 63: *Records Geol. Surv. India,* vol. I., 1868, p. 33.

(7) *Loc. cit.* (*Trans. Roy. Soc. S. Afr.,* 1922), p. 130.

present this form. The latter example has the constrictions rather angular on the periphery and therefore is much like any young *Hauericeras,* including the smaller syntype of *H. rembda,* though not the holotype of that species, with its very characteristic keel. Stoliczka's fig. 5 (pl. lxxi.) represents this emended *H. durga,* but not figs. 6, 7 (=*Puzosia compressa,* Kossmat) which came from the uppermost Albian Utatur Group, and therefore are not directly related to the form here discussed. *H. ugapuhi,* Marshall (1), which is also unkeeled, differs in proportions, and has a much higher umbilical wall, if the section is reliable.

Genus **KOSSMATICERAS**, de Grossouvre, 1901.

(Plate I., Fig. 2.)

There are two examples of a form which has great resemblance to *Amm. aemilianus,* Stoliczka (2) from the Aryalur Group of India, a species which was included by Marshall (3) in the separate genus *Maorites,* and by Kilian and Reboul (4) in the sub-genus *Madrasites,* whereas the similar *K. kalika* (Stoliczka), recorded by Dr. Whitehouse from Western Australia, was referred to *Gunnarites.* But the examples before me (which may quite well be identical with Dr. Whitehouse's form) are also close to *K. gemmatum* (Huppé) from Quiriquina, which was made the type of yet a third sub-genus (*Grossouvreites*) by Kilian and Reboul. The Australian form has a whorl-thickness of 33% as compared with 36% in *K. aemilianum* and 34% in *K. gemmatum,* while the width of the umbilicus is 23% (instead of 16% in *K. aemilianum* and 21% in *K. gemmatum*). As regards measurements the Australian form thus is less close to *K. aemilianum* than to *K. gemmatum* which was described by Steinmann (5) as being in some respects intermediate between *K. aemilianum* and *K. kalika.* But the ribbing at the beginning of the outer whorl in Steinmann's figure is far more distant than that of the examples before me, so that provisional reference to *K. aemilianum* is suggested, *K. kalika* showing crenulation of the ribbing. On the other hand, as Steinmann has shown, *K. gemmatum* (like the Australian form) has an incomparably more finely divided suture-line than any of the Aryalur species which is important, since *K. aemilianum* is generally recorded as from the uppermost Campanian (6).

The inner whorls of the smaller example are seen in section and they are only slightly more compressed than is the restored section given of *Holcodiscus tenuistriatus* by Paulcke (7). That species was described as less close to *Kossmaticeras gemmatum* than to *K. aemilianum,* and though the Australian and Patagonian forms are not identical, they undoubtedly are very closely related. I am recording the resemblance because Paulcke's

(1) *Loc. cit.* (*Trans. N.Z. Inst.,* vol. 56, 1926), p. 190, pl. 43, fig. 3, pl. 45, fig. 3.

(2) *Op. cit.* (Fossil Cephalopoda, Cret. Rocks, S. India), 1865, p. 141, pl. lxx., figs. 6-8.

(3) *Loc. cit.* (*Trans. N.Z. Inst.,* vol. 56, 1926), p. 174.

(4) Les Céphalopodes néocrétacées des îles Seymour et Snow Hill. *Wiss. Erg. Schwed. Südpol.-Exp.* 1901-03, vol. III., Lief. 6, 1909, pp. 25-6.

(5) Die Cephalopoden der Quiriquina-Schichten. *N. Jahrb. f. Min. &c. Beil.* Bd. X., 1895, p. 71.

(6) See e.g. Shimizu *loc. cit.* (*Journ. Shanghai Sci. Inst.*), 1935, p. 190.

(7) Die Cephalopoden der oberen Kreide Südpatagoniens. *Ber. Naturf. Ges. Freiburg* i. B., vol. XV., 1906, p. 224, pl. xvi., fig. 4.

species is from a bed higher in the sequence than the presumably Upper Campanian *Hoplitoplacenticeras* bed and succeeded only by *Baculites* wrongly attached to *B. vagina,* Forbes.

Genus **KITCHINITES**, Spath, 1922.

A septate whorl-fragment (Plate II., fig. 2) of a large ammonite (incomplete at restored diameter of about 115 mm.) from locality A, seems to differ from the much smaller *Holcodiscus karapadensis.* Kossmat (1), chiefly in size. There is the same type of costation, possibly a little coarser, in correspondence with the larger size, and the same flat and partly smooth whorl-side. The umbilical tubercles are not conspicuous, except at the very oblique constrictions, and the suture-line is similar and highly complex. But the two forms are not identical because at a diameter greater than that of the larger lectotype of *H. karapadensis,* the Australian fragment had at least a smooth venter, if not also a smooth whorl-side, as is shown by the impressed dorsal area. Moreover, the ventral chevrons of the outer whorl, directed forwards, are interrupted by a distinct siphonal groove, a feature known in certain forms of *Pachydiscus* (*e.g., P. valognensis,* Spath (2)). On the whole, the Australian ammonite is in the nature of a passage form between the Puzosidae and Pachydiscidae on the one hand and the Kossmaticeratidae on the other. The genus *Kitchinites* which is based on a species (*K. pondicherryanus,* Kossmat sp. (3)) first described as a *Holcodiscus* and considered to be nearly related to *Kossmaticeras theobaldianum* (Stoliczka), is thus undoubtedly a closer ally of the Australian form than is the more advanced *Holcodiscus karapadensis.* Until larger examples of *K. pondicherryanus* have been found, it is impossible to compare it accurately with the megalomorph form now described, but it seems to me that the latter represents the style of outer whorl that the typical (and less Puzosid) forms of *Kitchinites* must be presumed to have developed.

A second fragment, though labelled locality B, almost fits on to the first and appears to be a portion of the same ammonite.

Genus **PACHYDISCUS**, Zittel, 1884, emend. Grossouvre, 1893.

Half of a septate ammonite (Plate II., fig. 1) of about 100 mm. diameter has the whorl-shape of *P. gollevillensis* (d'Orbigny) (4), but slightly closer ribbing. It is thus much like *P. valognensis* (Spath) (5), which, in side-view, is indistinguishable from a "second example" of *P. gollevillensis* figured by A. de Grossouvre (6), but which is distinctly more compressed and more involute than the true *P. gollevillensis.* The Indian *P. crishna* (Forbes) (7) is probably an even closer ally. It is a more robust form than *P. compressus,* Spath (= *P. gollevillensis,* Kossmat (8), *non*

(1) *Loc. cit.* (part 2, 1897), p. 41, pl. viii., figs. 4a-c (lectotype), 2a, b.

(2) *Loc. cit.* (*Trans. Roy Soc. S. Afr.,* 1922), p. 122.

(3) *Op. cit.* (part 2, 1897), p. 40, pl. vi., figs. 6a-c.

(4) See in A. de Grossouvre: Les Ammonites de la Craie supérieure. *Mém. Expl. Carte géol. France,* 1893, p. 214, pl. xxix., figs. 4a, b.

(5) *Loc. cit.* (*Trans. Roy. Soc. S. Afr.,* vol. x., 1922), p. 122.

(6) *Loc. cit.* (1893), pl. xxxi., figs. 9a, b.

(7) Report on the Fossil Invertebrata from S India. *Trans. Geol. Soc.* (2), vol. vii., 1845, p. 103, pl. ix., fig. 2.

(8) *Op. cit.* (part 3, 1898), p. 97, pl. xv., figs. 1a-c.

d'Orbigny) and it differs from the Australian example in having all the ribs more distantly spaced and more prominent on the periphery, but it is equally evolute.

The portion of the next inner whorl which is preserved in the dorsal area shows a smooth periphery; and the very faint outer ribs of each side only appeared at a diameter of about 35 mm. This is the ornamentation of the young *P. egertoni* (Forbes) (1), but it is not nearly so robust as that of the immature *P. crishna,* wrongly united by Stoliczka (2) with the former. There can be no doubt that *P. egertoni* and *P. neubergicus* are not specifically identical, but they both belong to the group of *P. gollevillensis* as Matumoto (3) has recently again stated; and the compressed Australian form as well as the *P.* sp. cf. *compressus,* already recorded by Whitehouse, therefore belong to *Pachydiscus* in the most restricted sense (4).

In addition to the example of *P.* aff. *gollevillensis* (d'Orbigny) just discussed, there are in the present collection five fragments of a more inflated species of *Pachydiscus.* The thickness is constantly greater than the whorl-height (Th.: H. = 9:8) but in spite of this inflation the form is undoubtedly also a true *Pachydiscus,* for at a diameter of about 35 mm., the venter was still perfectly smooth and the secondary ribs of the ventro-lateral border appeared only at over 50 mm. The umbilical nodes were prominent, however, even in the very young stage, so far as can be seen, and at diameters of about 80 or 90 mm. they are very conspicuous, each then corresponding to about three distant secondaries. The appearance, therefore, is rather different from that of the similarly inflated *P. colligatus* (Binkhorst) (5) which has closer ribbing and loses the umbilical tubercles more quickly. The suture-line, however, is of the same type and since the internal lobes are visible in all the five specimens, I may add that the terminal prongs of the dorsal lobe are irregularly trifid. Like the inclination of the internal saddles, they can be of no systematic value, or be used to separate the inflated forms from the compressed species of *Pachydiscus* of the *neubergicus* group.

The Australian species just discussed is probably new; and I take it to be related to a gigantic form included by Stoliczka (6) in his *Amm. ootacodensis,* but renamed by Kossmat (7) *P. grossouvrei.* Unfortunately the inner whorls of this form are not known and those of its presumable European ally *P. wittekindi* (Schlüter) (8) are generally deformed by pressure,

(1) *Loc. cit.* (*Trans. Geol. Soc.,* 2, vol. vii.), 1845, p. 108, pl. ix., fig. 1.

(2) *Loc. cit.* (*Pal. Indica,* ser. 3, pt. 5), 1864, p. 104, pl. liii., fig. 4.

(3) Contributions to the Cretaceous Palaeontology of Japan. I. Preliminary Notes on the So-called *Parapachydiscus egertoni* (Forbes) from Japan. *Jap. Jour. Geol.,* 1936, p. 262.

(4) Spath: Problems of Ammonite Nomenclature. VI. The Genus *Pachydiscus.* Zittel. *Geol. Mag.,* 1939.

(5) See in Grossouvre: Descriptions des Ammonitidés du Crétacé supérieur &c. *Mém. Mus. Roy. Hist. nat. Belgique,* vol. iv., 1908, pls. iv., v. and vi. only.

(6) *Loc. cit.* (*Pal. Indica,* ser. 3, pt. 6), 1865, p. 109 (pars), pl. lvii. only.

(7) *Op. cit.* (Part 3), 1898, p. 101.

(8) Cephalopoden der oberen deutschen Kreide. Lief II. *Palaeontogr.,* vol. xxi., 1872, p. 67, pls. xxi and xxii (as *Amm. robustus*). If the young original of Pl. xxi., figs. 1-2 is correctly identified with the large lectotype of this species (*ibid.,* figs. 5-6), *P. wittekindi* acquires ventral ribs at an earlier stage than the Australian form, but the drawing is almost certainly unreliable (especially in the umbilical ribbing).

so that direct comparison is difficult. The Australian form may be somewhat intermediate between the *P. ootacodensis* and *P. ianjonaensis,* Collignon (1), recently described from Madagascar; but it is not the same author's *P. grossouvrei,* nor is it a form of *Eupachydiscus* in which genus the projected ribs may be strong or enfeebled on the venter, but are not interrupted in the siphonal line or thickened on each side of the venter.

Genus **DIPLOMOCERAS,** Hyatt, 1900.

There are four straight and septate fragments (smooth, internal casts) of an almost cylindrical species of *Diplomoceras* which must have reached considerable dimensions, the largest fragment having a ventro-dorsal diameter of about 55 mm. (and a lateral diameter of only 2 or 3 mm. less). The lytoceratid suture-line with its high external lobe is that of the very similar *D. cylindraceum* (Defrance) d'Orbigny sp. (2), in which the internal casts also show no trace of the ornamentation. While the four fragments here discussed might thus easily have been referred to the French species, there is a fifth, slightly curved fragment, apparently with an identical suture-line, which suggests caution in identifying the Australian form. For the last fragment, with a cylindrical cross-section, though largely a smooth cast, bears traces of the costation which was not only far more prominent and sharper than that of *D. cylindraceum,* but which was strongly oblique, the dorsal side being considerably retracted. The unusual sharpness of the ribs, however, may be due to the weathering (and replacement by limonite) and one of Schlüter's (3) examples of *Hamites cylindraceus* also shows strongly oblique ribs. Moreover, in a fine Vancouver specimen of *D. notabile* (Whiteaves) in the British Museum (No. C3486), while the internal cast is quite smooth, only the inner layer of test has the peculiar low and flattened ribs often seen in *Diplomoceras* (and well shown in d'Orbigny's figure), and the outermost layer shows rather sharper ribbing. Something similar is seen in a large fragment figured by Kossmat (4), which was wrongly attached to *Glyptoxoceras rugatum* (Forbes) and which may well be a portion of a *Diplomoceras.*

Genus **GLYPTOXOCERAS,** Spath, 1925.

There are apparently three or four species of this genus (which includes the so-called *Anisoceras* of the Valudayur Beds of India), but they are represented only by five body-chamber fragments, no trace of a suture-line having been observed.

The first species (Plate I., fig. 1) is represented by a straight portion 87 mm. long, which is slightly bent at the larger end, like comparable fragments from Pondicherry in the British Museum. The costation is blunt and distinctly oblique; there are seven ribs in a length equal to the diameter and there is very little attenuation of the ribbing on the dorsal side. The section is slightly compressed, the thickness being 19.5 mm. where the height = 21 mm. This fragment is probably close to *G. rugatum* (Forbes) (5) and dif-

(1) Ammonites campaniennes et maestrichtiennes de l'O. et du S. de Madagascar. *Ann. géol., Service des Mines,* fasc. ix., 1938, pl. ix., figs. 2, 4.

(2) *Pal Francaise, Terr. Crét.,* vol. i., 1842, p. 551, pl. cxxxvi.

(3) *Op. cit.,* Lief. v., 1872, pl. xxxi., fig. 10.

(4) *Op. cit.* (part i.), 1895, p. 146, pl. xix., fig. 8 (part only and rather diagrammatic; B.M. No. 10501, Geol. Soc. Coll.).

(5) *Loc. cit.* (*Trans. Geol. Soc.,* 2, vol. vii.), 1845, p. 117, pl. xi., figs. 2a-c.

fers chiefly in the inclination of the ribs; but this may be due to its being a body-chamber whereas the holotype of Forbes's species, refigured by Shimizu (1), is septate.

A second fragment has slightly less blunt and less oblique ribbing and is therefore still closer to *G. rugatum.* The attenuated costation of the dorsal side is slightly projected forward (in the form of a feeble sinus) whereas in the first fragment the dorsal ribs are regularly concave. The height is 20mm. where the thickness = 17mm., as in the holotype of Forbes's species, and what appears to be the apertural end is more distinctly bent than in the larger fragment first described. Neither, unfortunately, retains the final collar. The second example may not be definitely identifiable with *G. rugatum,* because it is so incomplete, but if I am right in associating it with a third fragment that retains its sharp ribbing, specific identity is almost certain.

In a fourth example, about 70mm. long and as slightly compressed as the other three, the ribs are more distantly spaced (five in a length equal to the diameter). In the large holotype fragment of *G. largesulcatum* (Forbes) (2) the ribbing is still more distant, but there are syntypes (in the Kaye and Cunliffe Collections) which scarcely differ from the Australian example; nor does one of Stoliczka's (3) examples of *G. largesulcatum,* representing part of the spiral portion like the fragment here discussed. *G.* (?) *nipponicum,* Shimizu (4), based on a *Hamites* sp. figured by Jimbo (5) and referred by Kossmat (6) to *G. largesulcatum,* differs chiefly in its circular section.

The last example of *Glyptoxoceras,* also a hook about 60mm. long, may be compared to *G. subcompressum* (Forbes) (7), although the ribbing is somewhat less close (seven ribs in a length equal to the diameter, instead of eight). The fragment is slightly malformed, the costae of one side being flexuous, but the compressed section and the sharpness of the ventral ribbing are characteristic.

Genus **EUBACULITES**, Spath, 1926.

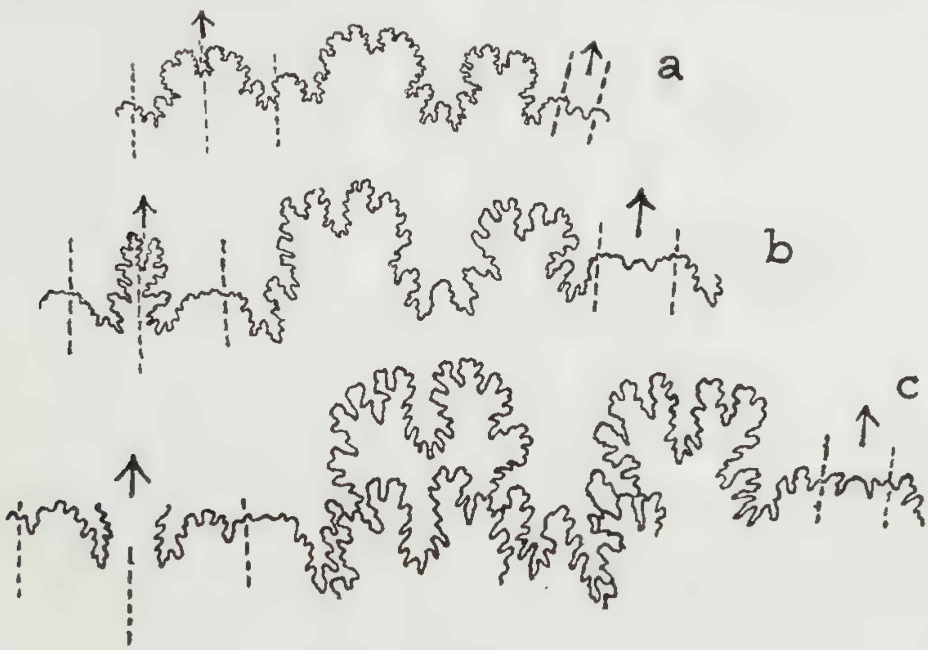
The group of *E. vagina* (Forbes) (8) is well represented, but while there are many very typical specimens of that group, there is nothing quite like Forbes's holotype (B.M. No. 10488, Geol. Soc. Coll.). The original drawing is incorrect in so far as the nodes are placed too near the double-edged ventral side. In reality, there is a longitudinal groove, which separates the smooth ventral from the nodate dorsal half of the side, and it is situated almost as near the middle of the shell, as in d'Orbigny's (9) figure of *Baculites ornatus* which is generally taken to be a synonym of *E. vagina.* Since Forbes's drawing shows the entire tabulate venter the narrowness of the smooth zone is particularly misleading. In the Australian forms which are here compared to *E. vagina,* there is no more trace of a longitudinal groove, or separation of the side into two different areas or zones, than there is in

(1) The Upper Cretaceous Ammonites so-called *Hamites* in Japan. *Proc. Imp. Acad. Tokyo,* vol. xi., 1935, p. 273, text-figs. 1-5.
(2) *Loc. cit.* (*Trans. Geol. Soc.,* 2, vol. vii.), 1845, p. 117, pl. xi., figs. 1a-e.
(3) *Loc. cit.* (*Pal. Indica,* ser. 3, pts. 10-13). 1866, p. 180, pl. lxxxv., fig. 8.
(4) *Loc. cit.* (*Journ. Shanghai Sci. Inst.*), 1935, p. 199.
(5) Beiträge zur Fauna der Kreide von Hokkaido. *Pal. Abh.,* vol. vi., 1894, p. 40, pl. vii., fig. 7.
(6) *Op. cit.* (part i.), 1895, p. 147.
(7) *Loc. cit.* (*Trans. Geol. Soc.,* 2, vol. vii.), 1845, p. 116, pl. xi., fig. 6.
(8) *Ibid.,* p. 114, pl. x., fig. 4.
(9) Voyage de l'Astrolobe, etc., 1847. Atlas Pal., pl. iii., figs. 3-6.

E. otacodensis (Stoliczka) (1), but the spacing of the crescentic nodes is closer even than in Forbes's type (about ten in a length of 90mm., as against nine in *E. vagina*) There is some variation, however, in the strength of the crescents, one example having them as prominent as in *E. otacodensis,* while two larger fragments are almost smooth. Some examples are curved as much as Forbes's type and the suture-line seems to be rather variable, especially as regards the prongs in the siphonal saddle on the tabulate venter. According to Steinmann (2) this median saddle bears a characteristic, deep funnel-shaped siphonal incision, and this is distinct enough in some of Darwin's South American forms before me; but in the Australian specimens under discussion, a bifid incision as in Forbes's type of *E. vagina* (Text-fig. *a.*) is commoner than a single prong, while in at least one fragment there are three equal incisions in the middle of the siphonal saddle.

E. otacodensis is represented by three typical examples, one of them represented in Plate I., fig. 3; its suture-line is reproduced in Text-fig. *b.* A variety of presumably the same form (with concave dorsum) shows nodes that do not come up to the dorsal edge and thus are more rounded and less prominent. The fragment of a gigantic individual (long diameter = 60mm.) and still septate (see Text-fig. *c.*), may belong to the same form, but if so, it has lost the ribs almost completely, like the two large fragments above referred to as *E.* aff. *vagina.*

Three small examples agree with Kossmat's (3) *E. simplex* which is separated specifically from *E. vagina* because it is a passage-form between *Eubaculites* and *Baculites* s.s.



Text-fig. 1.

Tracings (natural size) of Suture-lines of *Eubaculites.*

(*a*) *E. vagina* (Forbes) holotype (B.M., No. 10488, Geol. Soc. Coll.), Pondicherry, S. India. (*b*) *E. otacodensis* (Stoliczka). No. 20138, Dep. Geol. Univ. West. Aust., from Remarkable Hill (locality B), Cardabia Station, W. Australia, figured in Plate I., fig. 3. (*c*) *E.* sp. ind. Very large example, No. 20146, Dep. Geol. Univ., West. Aust., from the same bed (locality A).

(1) See especially in Kossmat, *op. cit.* (part i., 1895), p. 157, pl. xix., fig. 16.

(2) Die Cephalopoden der Quiriquina-Schichten. *N. Jahrb. f. Min,* etc. *Beil.* Bd. x., 1895, p. 91.

(3) Kossmat, *op. cit.* (part i., 1895), p. 156, pl. xix., fig. 13 (lectotype = *Baculites vagina,* var. *simplex*).

STRATIGRAPHICAL RESULTS.

The forty-three ammonoids described in the foregoing pages belong to the following sixteen species:—

A *Paraphylloceras* aff. *nera* (Forbes).
A *Phyllopachyceras forbesianum* (d'Orbigny).
B *Pseudophyllites* cf. *indra* (Forbes).
A *Hauericeras durga* (Forbes). (Plate II., fig. 3.)
*A *Kossmaticeras* sp. nov. ? aff. *aemilianus* (Stoliczka). (Plate I., fig. 2).
(?) *Kitchinites* sp. ind. (Plate II., fig. 2.)
B *Pachydiscus* aff. *gollevillensis* (d'Orbigny). (Plate II., fig. 1.)
*A, B *Pachydiscus* sp. nov. ? cf. *grossouvrei*, Kossmat.
B *Diplomoceras* aff. *cylindraceum* (Defrance) d'Orbigny sp.
B *Glyptoxoceras rugatum* (Forbes).
B *Glyptoxoceras* cf. *rugatum* (Forbes). (Plate I., fig. 1.)
B *Glyptoxoceras* aff. *largesulcatum* (Forbes).
B *Glyptoxoceras* cf. *subcompressum* (Forbes).
A, B *Eubaculites* aff. *vagina* (Forbes).
*B *Eubaculites otacodensis* (Stoliczka). (Plate I., fig. 3.)
*B *Eubaculites simplex* (Kossmat).

When I first examined this fauna I did not think that there was any difference between the forms from locality A and the assemblage from B, but it will be seen from the above list that the two localities have only two species in common, namely, *Pachydiscus* sp. nov. ? cf. *grossouvrei*, Kossmat, and *Eubaculites* aff. *vagina* (Forbes). The former belongs to a comparatively long-lived genus; and although *Eubaculites vagina* is more restricted, so far as we know, the possibility must not be overlooked that the two assemblages are not strictly contemporaneous. According to Dr. H. G. Raggatt (1) field-work and palaeontology agreed in suggesting that the same horizon was represented by the ammonite greensand over a distance of fifty miles along the eastern slopes of the Giralia-Cardabia Range. Yet the deposit is glauconitic and therefore almost certainly more or less condensed; moreover, the uncoiled genera *Glyptoxoceras* and *Diplomoceras* have been collected only at locality B.

The assemblage named by Dr. Whitehouse also does not quite support the view that the ammonoids from the greensand in question are strictly contemporaneous. Of course, it is possible that, as in the case of the differences noticed by Wilckens (2) among the assemblages from his three Quiriquina localities, conditions of life may have been slightly different. Dr. Whitehouse's fauna may include elements from localities rather far apart; but, in any case, it was said to include several "unnamed" genera, so that it cannot perhaps be too critically examined from our present point of view. Yet while *Parapachydiscus* (now *Pachydiscus*) cf. *compressus*, Spath, and *Gunnarites kalika* (Stoliczka) are probably near enough to *Pachydiscus* aff. *gollevillensis* and *Kossmaticeras* sp. nov. aff. *aemilianus*, of the above list respectively, to suggest approximate contemporaneity, and while three more forms (*Phyllopachyceras forbesianum* (d'Orbigny), *Pseudophyllites* cf. *indra* (Forbes), and *Eubaculites* aff. *vagina* (Forbes)) occur

(1) *Loc. cit.* (Jour. Roy. Soc., N.S. Wales, vol. lxx.), 1936, p. 160.

(2) Revision der Fauna der Quiriquina-Schichten. *N. Jahrb. f. Min.* etc. *Beil.* Bd. xviii., 1904, p. 273.

in the present fauna as well as in that studied by Dr. Whitehouse, the mention by that author of two forms of "*Schlüteria*" (now *Desmophyllites*) might seem suggestive. That genus is not represented in the collections before me, but since it is possible that the form attached to "*Schlüteria*" *rousseli*, Grossouvre, is a *Paraphylloceras* of the group of *P. nera*, and since species of *Desmophyllites* (of the *larteti* group) are known to occur in the Valudayur and Aryalur Groups of India as well as in many other Campanian-Maestrichtian deposits, they are not of real significance. What is more important is that Dr. Whitehouse's list also includes possibly heterochronous elements, as the dating of the fauna as Campanian alone indicates.

All the species in the above list, with one possible exception (*Diplomoceras*), have been identified with, or compared to, forms known from India; and whereas twelve are species from the Valudayur Group (which includes the Upper Maestrichtian *Sphenodiscus siva*, Forbes sp.) only four (marked with asterisks) are Aryalur forms. As it happens, however, localities A and B are more or less equally represented in either group and the fossils cannot therefore be differentiated off-hand into separate assemblages. Haug (1) included both the "*Anisoceras*" and *Trigonarca* beds of the Valudayur Group and the Aryalur Beds in the Maestrichtian, yet the latter contain reputed Campanian elements (*Pseudoschloenbachia, Kossmaticeras, Hauericeras gardeni*). On the other hand, both members of the Valudayur Group (and especially the higher *Trigonoarca* beds) are condensed deposits and almost certainly include forms of several horizons within the Maestrichtian.

I suggested in 1921 (2) that the three divisions of the Campanian and two zones of the Maestrichtian in Haug's sense probably represented only part of the true succession of horizons, i.e., that there might be unrecognised intermediate horizons; and in 1926 (3) I established an Upper Maestrichtian Sphenodiscan age and a Lower Campanian Hoploscaphitan age, with an intervening "Parapachydiscan" (*recte* Pachydiscan) age, covering both the Upper Campanian (4) and the Lower Maestrichtian. Since then a good deal of work has been done on the Ammonite faunas of the uppermost Cretaceous; and for example Shimizu's (5) provisional list of ammonite zones of Japan includes no fewer than eleven Campanian and Maestrichtian horizons. More recent work by Matumoto (6) was intended to show that the ranges of some of the species were less restricted than was previously assumed, and he suggested that the standard scale of Europe could not be directly applied to the stratigraphy of the North-Pacific region. But his account contains too many MS. names, while Shimizu's paper was rather hurriedly written, and it is therefore not easy to evaluate the work of these authors. But it appears probable that the deposits they studied do not include the Upper Maestrich-

(1) Traité de Géologie, vol. ii., fasc. 2, 1907, p. 1343. See also: Wilckens, Die Anneliden, Bivalven und Gastropoden der antarktischen Kreideformation. *Wiss. Erg. Schwed. Südpol-Exp.* 1901-03, vol. iii., Lief. 12, 1910, p. 107, etc.

(2) *Loc. cit.* (*Ann. Durban Mus.*, vol. iii.), 1921, p. 55.

(3) New Ammonites from the English Chalk. *Geol. Mag.*, vol. lxiii., 1926, p. 80 (Table).

(4) Besairie (*Mém. Acad. Malgache*, fasc. xxi., 1936, p. 92) adopted the name Submortoniceratan for the Upper Campanian or lower half of the Pachydiscan, but *Submortoniceras* is as characteristic of the Lower Campanian as *Hoplitoplacenticeras vari* is of the Upper Campanian.

(5) *Loc. cit.* (*Jour. Shanghai Sci. Inst.*), 1935, p. 216.

(6) A Biostratigraphic Study on the Cretaceous Deposits of the Naibuti Valley, South Karahuto. *Proc. Imp. Acad. Tokyo*, vol. xiv., 1938, p. 190.

tian (Sphenodiscan age); and though the two accounts differ considerably there can be no doubt that the Lower Maestrichtian of Japan is divisible into a number of horizons.

Which of these is (or are) represented in the West Australian assemblages here discussed cannot, however, be determined off-hand on the strength of the published successions. For example, while a *Pachydiscus* (*"Parapachydiscus"*) aff. *gollevillensis* (d'Orbigny) is said to occur in Shimizu's highest zone 31, various species of *Glyptoxoceras* and *Diplomoceras* occur much lower (zone 26) and *Kossmaticeras* (*Maorites*) *aemilianum* (Stoliczka) is recorded from the Upper Campanian zone 25. Since the latter is characterised by *Hauericeras gardeni* and *Pseudoschloenbachia*, typical elements of the Upper Campanian in Africa and Madagascar, it is almost certainly earlier than any part of the West Australian ammonite bed. Nor is there any resemblance between the assemblage here described and another (undescribed) Upper Campanian fauna before me from Egito, Angola, with *Hoplitoplacenticeras* (close to *Amm. dolbergensis*, Schlüter) as the characteristic element. It is true that *Pseudophyllites* occurs plentifully already in this fauna, associated with *Eupachydiscus* and a single *Zelandites* (=*"Varunaites"*) of Shimizu's zone 27; but the species of *Pseudophyllites* is a rather more primitive type than *P. indra*, and the numerous Nostoceratids and many examples of *Gaudryceras*, etc. give to that Angola assemblage an entirely distinct aspect.

Comparison of the Australian assemblage with a Maestrichtian fauna from Madagascar, recently described by Collignon (1), on the other hand, reveals more similarities. There are the ubiquitous *Pachydiscus gollevillensis*, *Diplomoceras cylindraceum*, and *Eubaculites vagina* (in addition to *Paraphylloceras* and *Desmophyllites*); and although *Pseudophyllites indra* and *Kossmaticeras aemilianum* are recorded with another Upper Campanian assemblage, Collignon pointed out that these forms were generally referred to the Maestrichtian. But I cannot agree with that author in considering the Fauna of Ianjona to be of Upper Maestrichtian age, nor with Besairie in describing *Eubaculites vagina* as an Upper Maestrichtian fossil. The mere fact that that species characterises the highest "Senonian" horizon in the whole of Madagascar shows that the Sphenodiscan (2) age (or Upper Maestrichtian in my chronology) is absent. Böse (3), who found that in Texas, *Pachydiscus* (*olim "Parapachydiscus"*) ranged up into the Sphenodiscan, even put relatively high beds with *Sphenodiscus* still in the lower portion of the Maestrichtian; and while I am not prepared to argue what later, non-ammonitiferous deposits should be included in the higher part of the Maestrichtian stage, I maintain that there is nothing known from either Madagascar, Japan or Western Australia to compare with the *Sphenodiscus*, *Coahuilites*, *Lybicoceras* or *Indoceras* faunas of North and Central America, Angola, Egypt, Transjordania (undescribed), Baluchistan, or Maestricht itself.

What has been said so far will suffice to show that while there is a possibility that the West Australian ammonites here discussed, may not belong to one narrow horizon (coming out of a five-foot bed of glauconitic deposit which must have been accumulated extremely slowly) they favour the view

(1) *Loc. cit.* (*Ann. géol. Service des Mines*, fasc. ix.), 1938, p. 59.

(2) See Spath, *loc. cit.* (*Geol. Mag.*, 1926), p. 80 (table).

(3) Cretaceous Ammonites from Texas and Northern Mexico. *Univ. Texas Bull.* No. 2748, 1927, pp. 185-6, etc.

that they are of Lower Maestrichtian rather than of Campanian age. The most abundant element at both localities is *Eubaculites,* a form known from such classical deposits (1) as those of Quiriquina in Chile and the Valudayur Beds of Pondicherry, apart from the Maestrichtian of Madagascar, but absent from the assemblages with Sphenodiscids already mentioned. The next most abundant elements are the uncoiled genera *Glyptoxoceras* and *Diplomoceras* (all from locality B), again reminiscent of the *"Anisoceras"* Beds of the Valudayur Group, a richly fossiliferous condensed deposit which forms a veritable lumachelle. In Japan also these genera occur only in a zone (26 of Shimizu) which has been placed at the base of the local Maestrichtian.

On the other hand, there are the few examples of *Kossmaticeras* (*Maorites* or *Gunnarites*) recorded both by Dr. Whitehouse and myself, and it is significant to me that forms of that genus are unknown from the Valudayur Group. Kossmat, it is true, recorded two species of *"Holcodiscus";* but one of these (*Amm. ? indicus,* Forbes) is a portion of the body-chamber of a *Scaphites,* as Forbes himself already suspected, and the second (*Holcodiscus pondicherryanus,* Kossmat) is the genotype of *Kitchinites,* also represented from Australia. As has already been shown, however, the examples here described (and probably belonging to a new form) are close to the Patagonian *Kossmaticeras tenuistriatum* (Paulcke) and especially the Quiriquina *K. gemmatum* (Huppé) whose very complex suture-line may well be taken to indicate a slightly later age than the common forms of *Kossmaticeras* of the Upper Campanian of, for example, New Zealand, Graham Land, and South Africa.

It is not to be expected that Upper Campanian and Lower Maestrichtian faunas are sharply separated or that local formations always respect the border-line between those two stages. Correlation with the standard European succession thus may often be difficult but I do not agree that the scale cannot be applied, for example, to Pacific deposits. There may be anomalies, such as those to which Besairie (2) has recently directed attention, but even these will, perhaps, disappear when the successions have been more carefully studied. Haug had correctly placed *Pachydiscus neubergicus* (Hauer) above *Hoplitoplacenticeras vari* (Schlüter), and if Besairie now finds that at Mitraiky in Madagascar, the former species occurs below *H. vari* I naturally suspect that one or both of the forms have been misidentified. The same applies to *Pachydiscus gollevillensis* which is said to occur both above and below *H. vari.* Moreover, Besairie himself wisely attached only secondary importance to the forms of the rather long-ranged genus *Pachydiscus* and it is generally admitted that the species are often very difficult to distinguish. *Hoplitoplacenticeras,* again, includes both Campanian (*H. vari*) and Maestrichtian (*H. lafresnayei,* d'Orbigny) forms, and the prolific group of *H. plasticus* (Paulcke) may well have existed at the actual period of change from Campanian to Maestrichtian time.

Although it is not yet possible to give a more final list of the successive ammonite faunas of the Lower Maestrichtian than on previous occasions, it is clear that the Australian assemblage formed part of one of these

(1) *Baculites occidentalis* (Meek) from the Vancouver deposits and from California is not so close to *Eubaculites vagina* as Kossmat thought, and at most transitional to that genus, while *B. vagina,* var. *cazadorianus,* Paulcke, from Patagonia, also seems to me quite different from the true *B. vagina.*

(2) *Loc. cit.* (*Mém. Acad. malgache,* fasc. xxi.), 1936, p. 92.

and that the ammonite bed was deposited during a temporary transgression of the sea over Western Australia. Such temporary transgressions took place on the fringes of other continents, in New Zealand, Chile and Patagonia, Graham Land; and even for Japan emergence or regression in Upper Maestrichtian times has been assumed by Shimizu. Since in Japan, as everywhere else, the Palaeogene deposits rest unconformably on the highest Cretaceous, it is difficult to judge how much sediment may have been removed before deposition again set in; but it is clear that the eighty-five feet of polyzoan limestone which succeed the ammonite bed in the Cardabia Range are only slightly younger than the latter, i.e., probably still Maestrichtian, and, in any case, represent only a very small portion of the enormous time interval between the Maestrichtian and the lowest Tertiary. Besairie (1) has recently shown that *Hercoglossa danica* co-existed in Madagascar with the highest ammonites known from there (which I believe to be Lower Maestrichtian) and he thus suppresses the Danian. Even supposing that his identifications of these late *nautili*, unlike those of his predecessors, are flawless, and that the Danian may itself turn out to be the equivalent of part of the Maestrichtian, I am not shaken in the conviction that there is still room for a mighty stage between the Maestrichtian and the Montian (or earliest Palaeogene). The *nautili* of the Campanian and Maestrichtian are already much like their Tertiary descendants and there is nothing surprising in one of these long-lived forms persisting after the last ammonites disappeared (in the Sphenodiscan age). *Hercoglossa danica* thus may not be a good zone fossil for the Danian, but once an undoubted sequence of post-Maestrichtian marine deposits has been discovered and worked out, it probably will not be necessary to have recourse to a *Nautilus* for zoning. Unfortunately, instead of showing "an almost unbroken sequence of sedimentation from Albian time to the present day" (2), the West Australian record is as incomplete as that of all other known successions and the time gap between the Maestrichtian and the lowest Tertiary is greater than in many other areas.

(1) *Loc. cit.* (*Mém. Acad. malgache*, fasc. xxi.), 1936, p. 94.

(2) See Raggatt, *loc. cit.* (*Jour. Roy. Soc. N.S. Wales*, vol. lxx.), 1936, p. 164.

EXPLANATION OF THE PLATES.

PLATE I.

Maestrichtian Ammonoidea from Remarkable Hill, Cardabia Range, Western Australia. Department of Geology, University of W.A.

Figs. 1a, 1b. **Glyptoxoceras** cf. **rugatum** (Forbes). Side- and ventral views, with outline whorl-section. Loc. B. No. 20136.

Figs. 2a, 2b. **Kossmaticeras** sp. nov. ? aff. **aemilianus** (Stoliczka). Side- and peripheral views. Loc. A. No. 20137.

Figs. 3a, 3b. **Eubaculites otacodensis** (Stoliczka). One of the fragments from Loc B, in side-view, and with outline whorl-section. For suture-line see Text-fig. 1b. No. 20138.

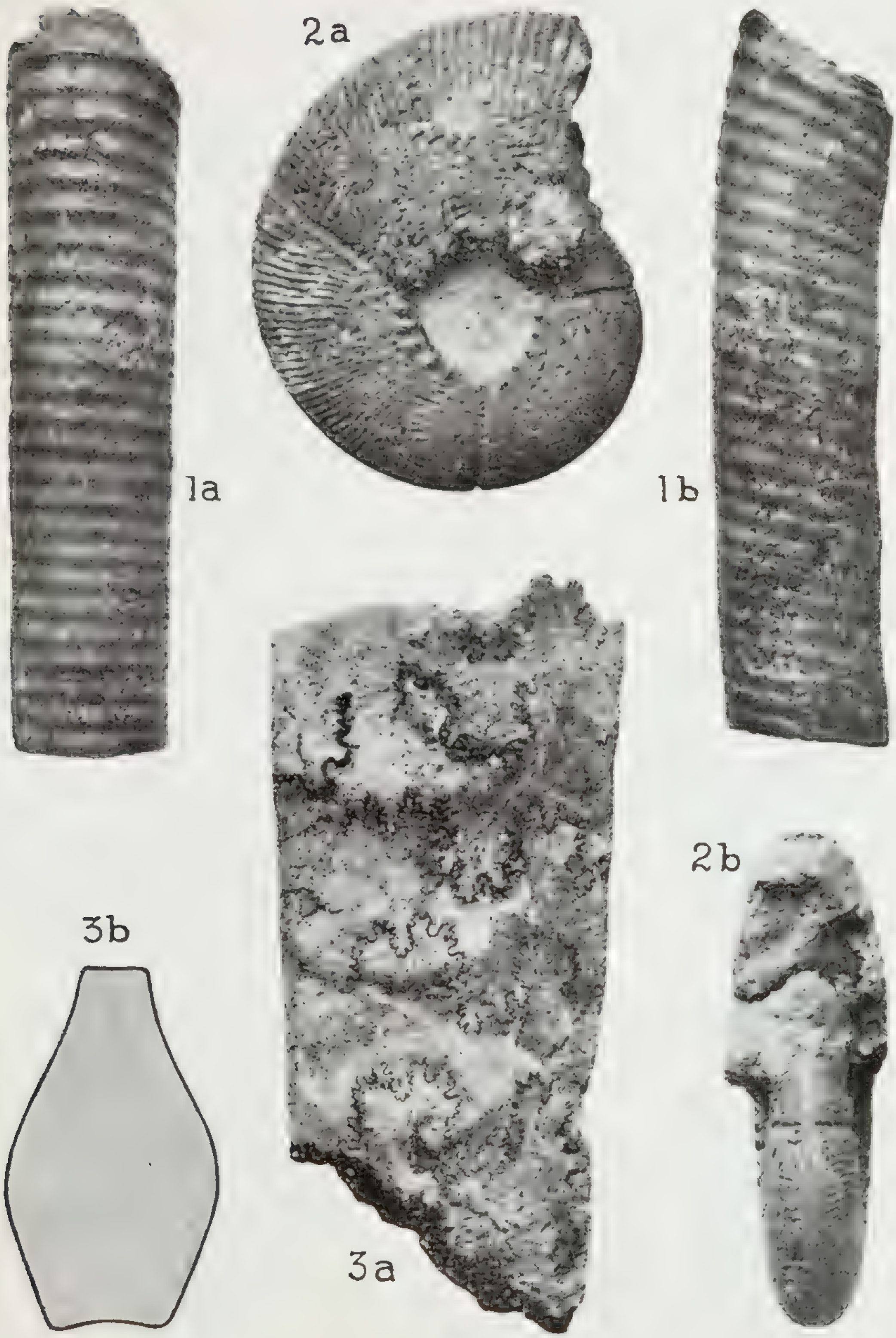


PLATE I

PLATE II.

Maestrichtian Ammonites from Remarkable Hill, Cardabia Range, Western Australia. Department of Geology, University of W.A.

Figs. 1a, 1b. **Pachydiscus** aff. **gollevillensis** (d'Orbigny). Fragment with perfectly smooth dorsal area. Outline whorl-section (b) at larger end. Loc. B. No. 20139.

Figs. 2a, 2b. **Kitchinites** sp. ind. Side- and ventral views. Excavated dorsal area apparently smooth. Loc. A. No. 20140.

Figs. 3a, 3b. **Hauericeras durga** (Forbes). Fragment with outline whorl-section (which should be more compressed). Loc. A. No. 20141.

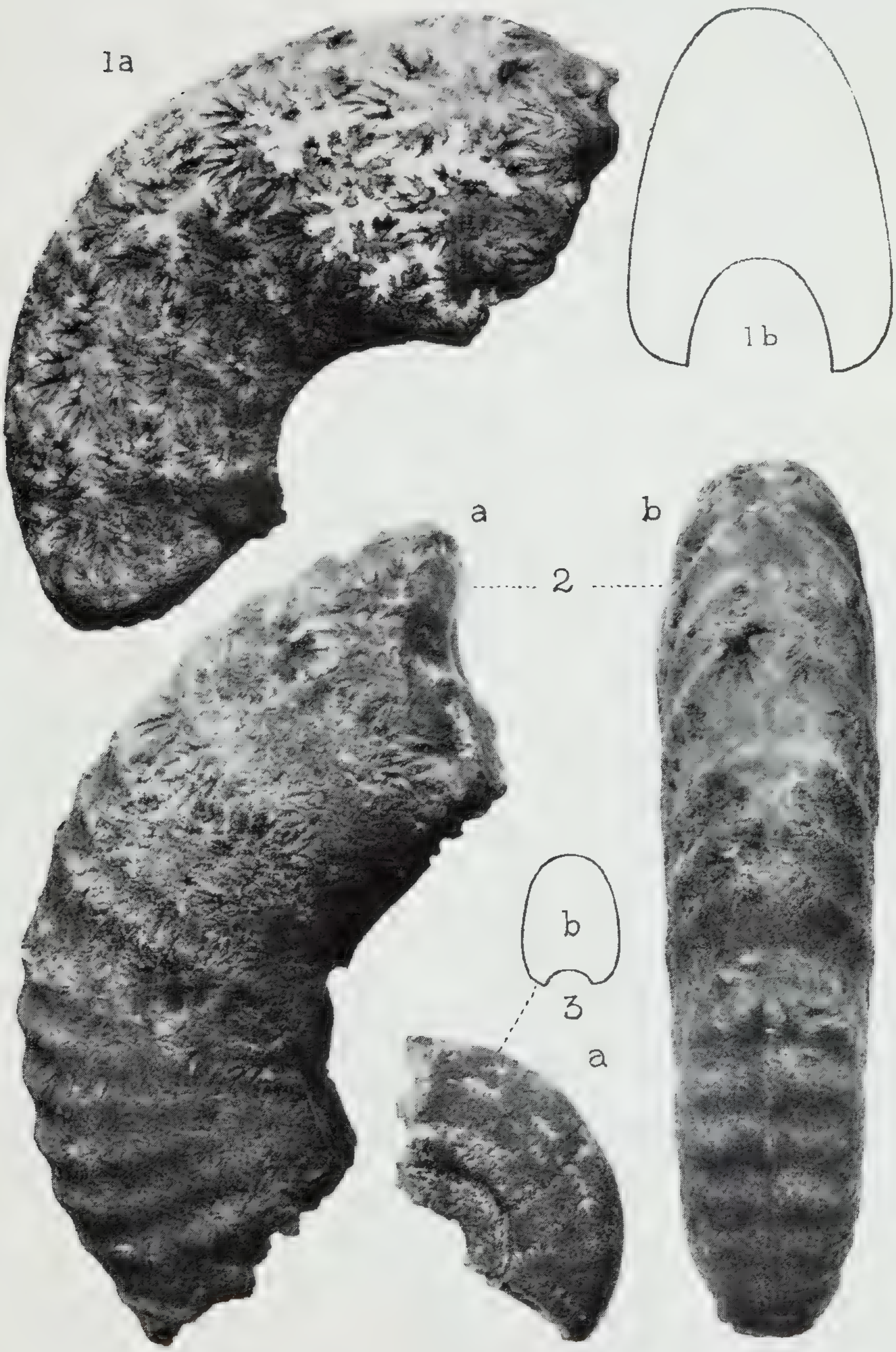


PLATE II.

6.—ACTINOSIPHONATE CEPHALOPODS (CYRTO-CEROIDA) FROM THE DEVONIAN OF AUSTRALIA.

By CURT TEICHERT.

Read: 14th November, 1939; Published: 28th August, 1940.

CONTENTS.

ABSTRACT.

In Western Australia the group of nautiloids with actinosiphonate structure is represented by *Conostichoceras* and by *Wadeoceras.* On the basis of recent finds, the latter genus can be redefined. Also, the possibility of sexual dimorphism in this genus is discussed and its commensalism with crinoids described. In Victoria, the actinosiphonate group is represented by *Phragmoceras subtrigonum* McCoy which is here referred to the genus *Danaoceras* Foerste, as well as by a species of doubtful generic relationships, *Danaoceras ? bindiense,* both from the Middle Devonian of Gippsland.

ACTINOSIPHONATE CEPHALOPODS IN WESTERN AUSTRALIA.

In a recent paper I drew attention to the occurrence of actinosiphonate cephalopods (Cyrtoceroidea) in Western Australia where this group is represented by the probably Middle Devonian *Conostichoceras hardmanni* and the Upper Devonian *Wadeoceras australe,* both from strata in the Kimberley District in the northern part of the State (Teichert, 1939). The genus *Wadeoceras* was established in this paper on a rather fragmentary phragmocone. In July, 1939, I had the opportunity of visiting some of the Devonian localities in the Kimberley District and spent a day in the vicinity of Mt. Pierre. On this occasion I secured well preserved specimens of *Wadeoceras* so that the genus can now be fully described.

It was found that *Wadeoceras* occurs in the Middle Goniatite beds of the Kimberley District where it is associated with the goniatites *Cheiloceras, Tornoceras,* and *Dimeroceras.* The age of these beds corresponds to the Oberdevonstufe II or *Cheiloceras* stage of the European standard section as has been explained elsewhere (Teichert, 1940).

I wish to take this opportunity to express my gratitude to Mr. L. M. Waterford and to Dr. R. T. Prider who most readily rendered valuable assistance in the field, also to the Freney Oil Company, Ltd., Perth, who very kindly provided the facilities for my visit to the Kimberley District. The plates and text-figures in this paper were prepared by Mrs. Gertrude Teichert.

SEXUAL DIMORPHISM IN *WADEOCERAS.*

As will be more fully described below, *Wadeoceras* is represented in the new collection by two forms which resemble each other in many respects. One of the specimens (No. 19485) is so similar to the holotype of

Wadeoceras australe that the redefinition of the genus is largely based on this specimen. Another almost complete specimen (No. 19486) is very similar to typical *Wadeoceras australe* with which it agrees in the general shape and the proportions of the conch and in the position and structure of the siphuncle. It differs, however, in its larger size and in the greater length of its camerae. Both forms are represented by gerontic individuals, characterised by the shortness of the last camera and by the presence of the basal thickening of the wall of the living chamber ("basal zone" of Flower, 1938, p. 9). The larger specimen was found in a layer 12 feet above the layer which contained the smaller specimen. A fragment of another specimen of the smaller type (No. 19497) was found 63 feet above the large specimen (19486) and 40 feet below the lowest beds containing *Sporadoceras*. The larger specimen might represent a different species, but it seems more probable that we are here concerned with a case of sexual dimorphism.

Sexual dimorphism in fossil nautiloids was first discussed by Ruedemann (1919, 1921, 1926) when he studied a series of specimens of *Oncoceras* from the Ordovician Utica shale of New York. The specimens could be divided into three groups, two of which resembled each other very closely except for their size, and which Ruedemann, therefore, referred to one and the same species, *Oncoceras pupaeforme*. In view of the fact that in living cephalopods the males are usually more slender or smaller than the females, Ruedemann regarded the smaller specimens as the males and the larger specimens as the females of this species. In 1926 Foerste (p. 355) explained differences in the dorsal collar of specimens of *Inversoceras* as possibly indicating sexual differences.

The question of sexual dimorphism in cephalopods was again discussed by Flower in 1938 (pp. 7-8), who called attention to possible cases among species of *Ovoceras, Brevicoceras,* and *Verticoceras* from the Devonian of New York. As a matter of fact, as Flower justly pointed out, "the existence of sexual dimorphism in extinct forms, and particularly in extinct forms which have no close living relatives, is not a thing that can be categorically asserted or denied," but the conditions in *Wadeoceras* agree well with cases which are thought to indicate existence of sexual dimorphism in other breviconic genera. In all the examples quoted by Flower the difference in size between the supposed females and males is not as pronounced as in Ruedemann's original example of *Oncoceras pupaeforme*. If our interpretation is to be accepted the sex distinctions in *Wadeoceras australe* are more marked than in the Devonian breviconic genera referred to by Flower and more similar to those of *Oncoceras pupaeforme*.

COMMENSALISM.

On both conchs of *Wadeoceras* described below there are crinoid roots attached to the shell, varying in size between one and six millimetres in diameter. These roots are irregularly scattered over the surface of the conch. It is therefore probable that they were attached to the conch while the animal was still alive, and it must be assumed that the animal either crawled along carrying its conch elevated in an inverted position, or, what is more likely, that it led an actively motile, nectonic life. As far as I am aware, cases of commensal crinoids adhering to nautiloid cephalopods have only been described once before, viz., by Ganss in 1937, who gave an excellent description of crinoid and cystoid roots attached to Ordovician orthoceroid and endoceroid conchs found in the Pleistocene drift of northern Germany.

Furthermore, the Department of Geology of the University of Western Australia possesses a specimen of a large *Pinacoceras* from the Upper Triassic of Bihati, Timor, invested by numerous crinoid roots on both sides of the conch. Similar cases among Triassic and Liassic ammonites were described by Ganss in a previous paper (1935). Miller, in 1932, observed that on the whole, commensal organisms are very rarely found on tetrabranchiate cephalopods and the occurrence of commensal crinoids on shells of Devonian *Wadeoceras* is, therefore, rather unusual and worth mentioning. It may be added that the beds containing *Wadeoceras* contain a fair amount of isolated crinoid stems and roots, though no parts of crowns have as yet been found.

ACTINOSIPHONATE CEPHALOPODS IN VICTORIA.

In my paper referred to above I suspected that *Phragmoceras subtrigonum* McCoy from the Middle Devonian of Victoria might be another representative of *Wadeoceras* in Australia. Thanks to the kindness of Messrs. D. J. Mahony and R. A. Keble, of the National Museum, Melbourne, I have since had the opportunity of studying the holotype and other specimens of this species. From these studies it was at once evident that the Victorian species belongs to a different genus, and it is here referred to the genus *Danaoceras* Foerste which has so far only been known from the Middle Silurian of Bohemia. *Danaoceras* is closely related to *Wadeoceras,* as pointed out by me in 1939, and both belong to the same family Archiacoceratidae. The geographical range of actinosiphonate cephalopods is thus extended right across the Australian continent from its north-western part to the south-east corner.

The group is also represented by one specimen from the Middle Devonian of Bindi which is a new species of somewhat doubtful generic affinities, and which is here described as *Danaoceras* (?) *bindiense* sp. nov.

In Victoria, *Danaoceras* is associated with several other species of nautiloids which. however, are in need of being restudied (1).

Danaoceras subtrigonum is characterised by a great number of endosiphuncular lamellae. These lamellae are lined with secondary deposits, apparently similar to those of *Jovellania* from the Devonian of France, as described by Dechaseaux in 1937.

PALAEONTOLOGICAL DESCRIPTIONS.

Genus **WADEOCERAS** Teichert.

Genotype—*Wadeoceras australe,* Teichert, 1939, p 111.

Emended diagnosis.—Endogastric porterioceroid cyrtoceracones with actinosiphonate siphuncle and constricted, phragmoceroid aperture with wide hyponomic sinus. Segments of siphuncle wider than long, but not inflated between the septa.

As has been pointed out before (Teichert, 1939) the genus is related to *Danaoceras* Foerste and to *Archiacoceras* Foerste. In the general shape of the conch it recalls *Poteriocerina* Foerste which, however, is an exogastric form.

(1) In 1939 (p. 106) I made reference to a few incorrect identifications of *Actinoceras* from Devonian rocks of the Australasian region. To these has to be added, in all probabality, the recorded occurrence of *Actinoceras* in the Middle Devonian of Victoria and New South Wales (Benson, 1922, p. 114). I have examined one specimen, thus determined, from the Devonian of Cavan, Murrumbidgee River, Yass District, New South Wales (No. 7010, National Museum, Melbourne) which is an indeterminable fragment of a straight phragmocone.

Wadeoceras australe Teichert.

Plate I., Figs. 2, 3; Plate II., Figs. 4-6.

1939—*Wadeoceras australe,* C. Teichert, Jour. Roy. Soc. West. Austr., vol. 25, pp. 111-112, pl. 1, figs. 2, 3.

The holotype of this species is a portion of a phragmocone. There are now available two almost entire specimens which will be described here.

(1) No. 19485, Department of Geology, University of Western Australia, from strata 114 feet below the lowest bed containing *Sporadoceras,* on east side of crossing of the old road from Fitzroy Crossing to Hall's Creek over a small creek about half a mile west of the crossing of the same road over Mt. Pierre Creek. (Pl. I., fig. 3; Pl. II., fig. 4.)

This is an internal mould, 82 mm. long, consisting of portion of a phragmocone with 13 camerae and the living chamber which is 33 mm. long. The initial part of the phragmocone is missing. The dorso-ventral diameter increases from 26 mm. to 51 mm. at the second-last camera; it then remains constant until a distance of about 9 mm. from the base of the living chamber whence the diameter decreases towards the aperture. The lateral diameter increases from 26 mm. to 56 mm. at a distance of about 9 mm. from the base of the living chamber; at the second last camera the diameter is 50 mm. It will be seen, therefore, that in the dorso-ventral section the greatest gibbosity is reached in the upper part of the phragmocone whereas the greatest diameter in the lateral section is reached distinctly above the base of the living chamber. Exact shape and dimensions of the aperture cannot be determined, but its maximum lateral diameter must have been approximately 43 mm. The longitudinal outline of the conch is evenly convex dorsally; it is slightly concave along the greater part of the ventral side of the phragmocone and straight along the adoral part of the phragmocone and the adapical part of the living chamber. The dorsal side of the conch is slightly flattened, ventral and lateral sides evenly convex. The septa are only slightly concave. The sutures rise laterally, owing to the curvature of the conch, and are almost straight across the dorsum. The distance between the sutures along the dorsal side increases from about 3 mm. to 5.3 mm., but the second-last camera is only 4.1 mm., the last camera only 3.0 mm. long. The corresponding distances along the ventral side are approximately three-fifths of the distances along the dorsal side.

At the base of the living chamber there is an impressed zone in the mould immediately above the last septum. In some places remnants of the shell are still preserved in this depression which is due to an internal thickening of the shell in this place. Similar features have been noted in nautiloids, particularly in gomphoceroid conchs, by earlier observers (J. Hall, J. Barrande and others) and were lately described in detail by Flower (1938), who considers the thickening of the basal zone of the wall of the living chamber as a gerontic feature.

The siphuncle is close to the ventral wall, but no details can be seen.

(2) No. 19486, Department of Geology, University of Western Australia, from strata 12 feet above the preceding specimen in the same locality. (Pl. I., fig. 2; Pl. II., fig. 5.)

This is a larger specimen, 118 mm. long, with the shell still preserved, consisting of portion of a phragmocone with 18 camerae and an almost complete living chamber which is 49 mm. long. The dorso-ventral diameter

increases from 22.5 mm. to 63 mm. at the second-last camera. It still increases very slightly along the adapical part of the living chamber, but this is probably due to the fact that most of the shell is worn away along the upper part of the phragmocone whereas the shell of the living chamber is well preserved. There is probably no true increase in thickness of the conch above the second-last septum. The lateral diameter increases from 22 mm. to 68 mm. at the base of the living chamber and to 71 mm. at a distance of 10 mm. above the base of the living chamber. The longitudinal outline of the conch along the dorsal side is evenly convex, the ventral outline concave in the adapical part of the phragmocone and straight in the adoral part of the phragmocone and in the adapical part of the living chamber. The lateral outline is very slightly concave in the adapical part of the phragmocone, but straight along the greater part of the phragmocone and the adapical part of the living chamber. The cross-section is evenly rounded ventrally and laterally, somewhat flattened dorsally. The sutures rise along the lateral sides and are straight across the dorsum. The distance between the sutures when measured along the ventral side increases from 1.4 mm. to 5.8 mm. in the second-last camera; the last camera is only 3.4 mm. long. Measured along the dorsal side the distance of the sutures is about 1.4 times longer.

The siphuncle is quite close to the ventral wall of the conch. Its diameter is 1.5 mm. at the adapical end of the specimen, but increases rapidly to 4 mm. in the tenth camera.

The shell of the conch is apparently smooth and is rather heavy. Around the base of the living chamber, there is an internal thickening of the wall, forming a distinct ring which is 4.2 mm. wide; the inner side of the ring is vertically ribbed. The shell is here 4.0 mm. thick, whereas the normal thickness of the wall of the living chamber is slightly less than 3 mm.

The aperture is only partly preserved but can be reconstructed with a fair degree of certainty (Fig. 1). It is strongly contracted laterally to a minimum width of probably not more than 32 mm., whereas the dorso-ventral diameter of the aperture must be at least 58 mm. The shape is phragmoceroid with a straight dorsal outline, slight expansion between the dorsum and the centre to a width of at least 40 mm., a strong contraction between the centre and the venter and a strong, but probably rather wide hyponomic sinus.

Fig. 1.—Outline of the aperture of *Wadeoceras australe* Teichert. Same specimen (No. 19486) as Pl. I., fig. 2, and Pl. II., fig. 5.

The differences between this specimen and the one described before are regarded as indicating sex distinction rather than specific separation.

(3) A fragment of a specimen of the smaller type was found 63 feet above the preceding specimen. The cross-section of its siphuncle (pl. II. fig. 6) is slightly oval with a more narrowly rounded ventral side and the presence of simple, short and not very numerous radiating lamellae is clearly indicated.

Genus **DANAOCERAS** Foerste.

Genotype—*Cyrtoceras danai* Barrande.

Danaoceras subtrigonum (McCoy).

Plate III., Figs. 7-9, Plate IV., Fig. 11.

1876 *Phragmoceras subtrigonum*, F. McCoy, Prod. Pal. Vict., Dec. IV., pl. 35, Figs. 6, 6a.

Description of holotype (No. 1290, National Museum, Melbourne): The specimen is an internal mould of portion of a phragmocone and a large part of the living chamber. The dorso-ventral diameter increases from 43 mm. at the adapical end to 60 mm. at the base of the living chamber and to 67 mm. at a distance of 20 mm. from the base of the living chamber; the corresponding figures for the lateral diameter are 40, 56 and 61 mm. Thus, the phragmocone expands at a quicker rate than the living chamber. As far as the latter is preserved there is no sign of contraction and it seems unlikely that the specimen possessed a contracted aperture. The ventral outline of the specimen is slightly, but evenly concave, its dorsal outline convex. The lateral outlines of the phragmocone are slightly convex, those of the living chamber almost straight with diverging sides. The cross-section is oval with a broadly rounded dorsal and narrowly rounded ventral side. The surface of the mould is ornamented by weak longitudinal ridges on the ventral and lateral sides; the absence of this ornamentation on the dorsal side may be due to weathering. The ridges are about 1.5 mm. apart at the base of the specimen, their distance increases adorally in accordance with the expansion of the conch. The septa are moderately convex, the sutures almost straight, except for a slight ventral saddle. Measured along the dorsal side the distance between successive sutures is 6.8, 5.9, 6.7, 4.8, 3.3, 3.7, 3.5, and 5.5 mm. It seems, therefore, that the specimen is not yet fully mature. Ventrally, the distance between the septa is approximately two-thirds the distance measured along the dorsal side.

The siphuncle is close to the concave side of the conch; at the bases of the specimen it is 2 mm. distant from the wall of the conch. In a section approximately parallel to the septum in this place the dorso-ventral diameter of a segment is 8.7 mm., its lateral diameter 5.7; the cross-section is elliptical. Attached to the inner side of the wall of the segments are a great number of lamellae, directed towards the centre of the siphuncle. Lamellae of about 1 mm. length alternate with lamellae 0.5 mm. or less long. In transverse section most of these lamellae are not straight, but somewhat irregular and bent. The longer lamellae usually divide into two or three branches. The lamellae consist of the same material as the walls of the segments and emerge without discontinuity from them. They are covered by a thin layer of apparently stereoplasmatic deposits which probably correspond to the deposits observed by Dechaseaux (1937) on the endosiphuncular lamellae of *Jovellania*.

Additional material: In another specimen from the type locality a longitudinal section through an earlier part of the phragmocone is exposed (fig. 2). The dorso-ventral diameter of this species increases

from about 13 mm. to 32 mm. The septa are only preserved in the adapical part of the specimen where they are 1.5 mm. apart. The ventral outline is slightly concave, the dorsal outline slightly convex. The siphuncle is close to the ventral wall. The segments are only slightly expanded between the septa. The first of the segments which can be measured is 1.5 mm. long and 1.4 mm. wide; the last segment preserved is 3.0 mm. long and 3.8 mm. wide. Vertical lamellae are visible in the interior of the siphuncle. This specimen represents a portion of the phragmocone almost in the immediate adapical continuation of the phragmocone of the holotype.

Fig. 2.—Cross-section of adapical part of phragmocone of *Danaoceras subtrigonum* McCoy. Buchan, East Gippsland, Victoria. National Museum, Melbourne. 2.3 ×.

Comparisons and affinities: This species agrees in many respects with the holotype of *Danaoceras, D. danai* Barrande, from the Middle Silurian of Bohemia, an endogastric cyrtoceracone with unconstricted aperture (Foerste 1926, p. 246). It differs from that species in the presence of weak internal longitudinal ribs and probably also in the relative width of the siphuncle which is described as cylindroid "not only along the lower part of the phragmocone, but also farther up" (Foerste 1926, p. 347). However, until a detailed study of the structure of the siphuncle of the genotype has been made, the two species can be regarded as congeneric.

Occurrence: In the Middle Devonian limestone of Buchan, Gippsland, Victoria.

Danaoceras (?) bindiense sp. nov.

Plate I., Fig. 1, Plate IV., Figs. 10, 12.

Description of holotype (No. 1293, National Museum, Melbourne): The specimen is an internal mould of portion of a phragmocone with ten camerae and the basal part of the living chamber. The dorso-ventral diameter of the

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phragmocone increases from 28 mm. to approximately 43 mm.; the actual figures are probably 2 or 3 mm. larger, since the ventral side of the mould is somewhat weathered and the siphuncle exposed. The lateral diameter of the phragmocone increases from 27 mm. to approximately 44 mm., and the cross-section, therefore, must have been very slightly compressed in the original conch. The conch seems to be straight, but may have been slightly concave ventrally, and the living chamber which in one place is preserved for a length of 15 mm. expands at almost the same rate as the phragmocone. The sutures are straight and the height of the successive camerae is 3.5, 3.5, 3.2, 3.4, 3.0, 3.3, 2.7, 2.5, 3.7, 3.0 mm. The septa are very slightly convex. The siphuncle was probably not more than about 1 mm. from the ventral wall of the conch. In the interior of the siphuncle there are a number of vertical lamellae, numbering approximately 25, which reach from the periphery very close to the centre of the siphuncle. The segments of the siphuncle are only slightly expanded between the septa. The lateral diameter of the second segment of the siphuncle is 5 mm.

The shell of the living chamber is preserved in one place where it shows transverse striation by growth marks.

Comparisons and affinities: The holotype of this species was originally listed as *Phragmoceras subtrigonum* (Benson 1922, p. 114; Hills 1935, p. 113). Its generic affinities cannot at present be satisfactorily explained, but it is certainly different from any other nautiloid cephalopod so far known from the Devonian of Australia. Its relationships to *Danaoceras subtrigonum* are not particularly close, except for the marginal position of the siphuncle, its probably endogastric affinities, and its apparently unconstricted aperture. The difference is in the smaller degree of curvature, if, indeed the Victorian specimen is curved at all, in the shape of the segments of the siphuncle, in the structure of the siphuncle, in the absence of longitudinal ribs on the mould, and in the almost circular cross-section of the conch. If future finds should show that the species is erect and has a circular cross-section and an unconstricted aperture, it would probably represent a new genus of actinosiphonate cephalopods.

Occurrence: Middle Devonian of Bindi, East Gippsland, Victoria.

PLATE I.

All figures natural size.

Fig. 1. **Danaoceras ? bindiense** sp. nov. Holotype. Adapical view. Middle Devonian, Bindi, East Gippsland, Victoria. No. 1293, National Museum, Melbourne.

Fig. 2. **Wadeoceras australe** Teichert. Supposed female, lateral view. Upper Devonian, near Mount Pierre, West Kimberley District, Western Australia. No. 19486, Department of Geology, University of Western Australia.

Fig. 3. **Wadeoceras australe** Teichert. Supposed male, lateral view. Same locality as Fig. 2. No. 19485, Department of Geology, University of Western Australia.

PLATE I.

PLATE II.

Fig. 4. **Wadeoceras australe** Teichert. Supposed male, ventral view. Nat. size. Same specimen as Pl. I., Fig. 3.

Fig. 5. **Wadeoceras australe** Teichert. Supposed female, ventral view. Nat. size. Same specimen as Pl. I., Fig. 2.

Fig. 6. **Wadeoceras australe** Teichert. Cross-section of siphuncle showing radiating lamellae, 9 ×, made from another male specimen, found 63 feet above No. 19486. No. 19497, Department of Geology, University of Western Australia.

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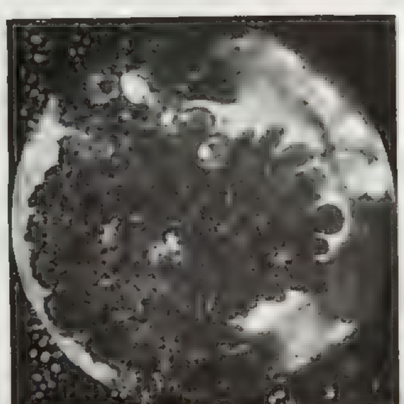

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PLATE II.

PLATE III.

All figures natural size.

Figs. 7-9. **Danaoceras subtrigonum** McCoy. Holotype. Ventral, adapical, and lateral views, nat. size. Middle Devonian, Buchan, East Gippsland, Victoria. No. 1290, National Museum, Melbourne.

(N.B.—The siphuncle did not appear on the original photo of Fig. 8 and is shown diagrammatically; its structure is identical with that shown on Pl. IV., Fig. 11.)

3

2

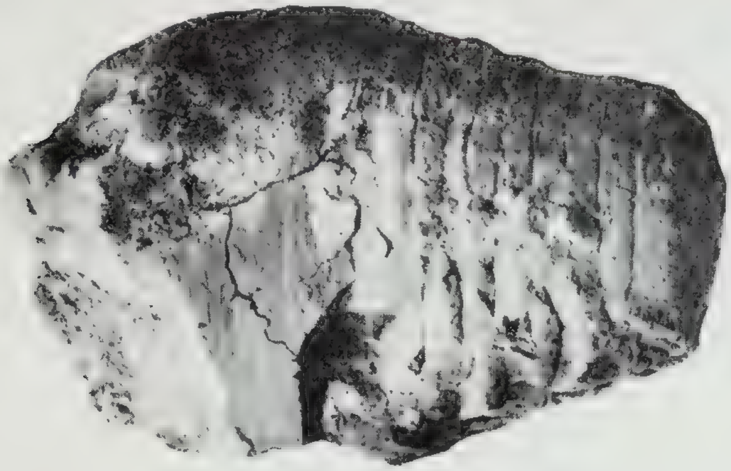
1

PLATE III.

PLATE IV.

Figs. 10, 12. **Danaoceras ? bindiense** sp. nov. Holotype. Ventral and lateral views, nat. size. Same specimen as Pl. I., Fig. 1.

Fig. 11. **Danaoceras subtrigonum** McCoy. Cross-section of siphuncle of another specimen, 7 ×. Same locality as holotype. No. 1291, National Museum, Melbourne.



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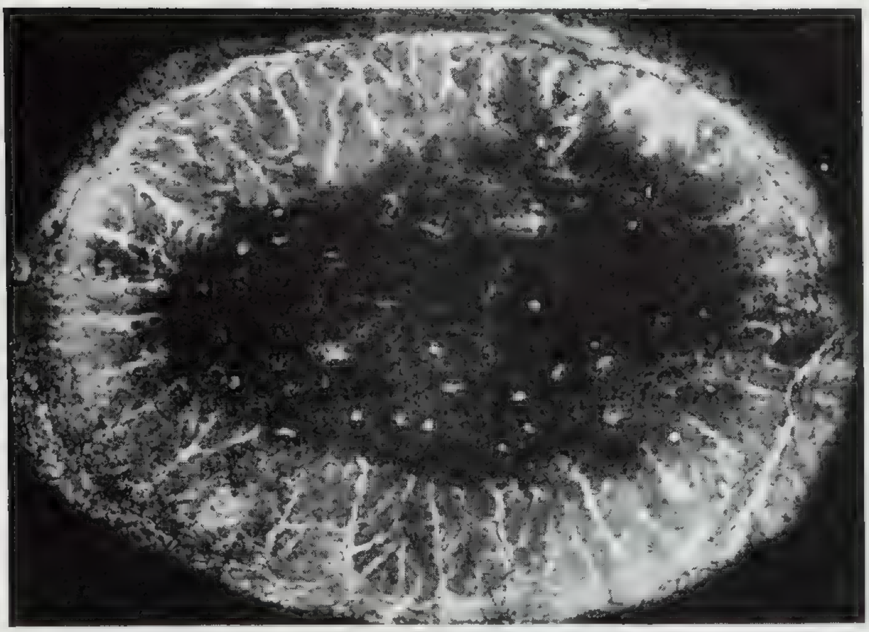

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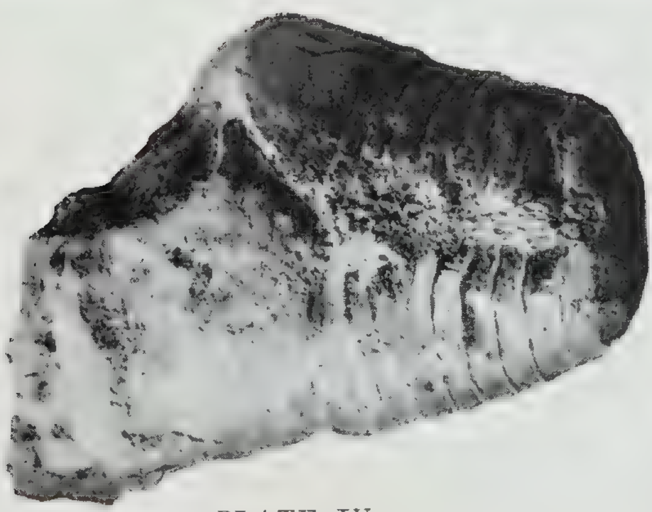

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PLATE IV.

7.—SOME CAMBRIAN BASALTS FROM THE EAST KIMBERLEY, WESTERN AUSTRALIA.

By A. B. EDWARDS, Ph.D., D.I.C., and E. de C. CLARKE, M.A.

Read: 10th October, 1939; Published: 28th August, 1940.

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I. NOTES ON FIELD OCCURRENCE.

By E. de C. Clarke, University of Western Australia.

INTRODUCTION.

The Kimberley Land Division, which has an area of 144,000 square miles, occupies the northernmost part of Western Australia (Fig. 1). In it have been found representatives of nearly all the formations which occur in other parts of the State, and it has, in addition, rocks of Cambrian and Devonian age. In its south-west part is a rather unique suite of alkaline eruptives, and in its northern and eastern parts a considerable development of basalts.

The basalts of the eastern part, with which we are here concerned, extend into Northern Australia, and occur over a large area between latitudes 15° and 19°, and longitudes 128° and 130° (Fig. 2). Some of them, at least, are of Cambrian age, and are reported to attain a thickness of as much as 3,000 feet in some localities.

The Kimberley is more than 1,000 miles from the main centres of population in Western Australia. Until the recent development of air services, the quickest means of reaching it was by a sea voyage of about ten days. Population and means of land communication are still very meagre, and, although the first gold discoveries of any importance in Western Australia

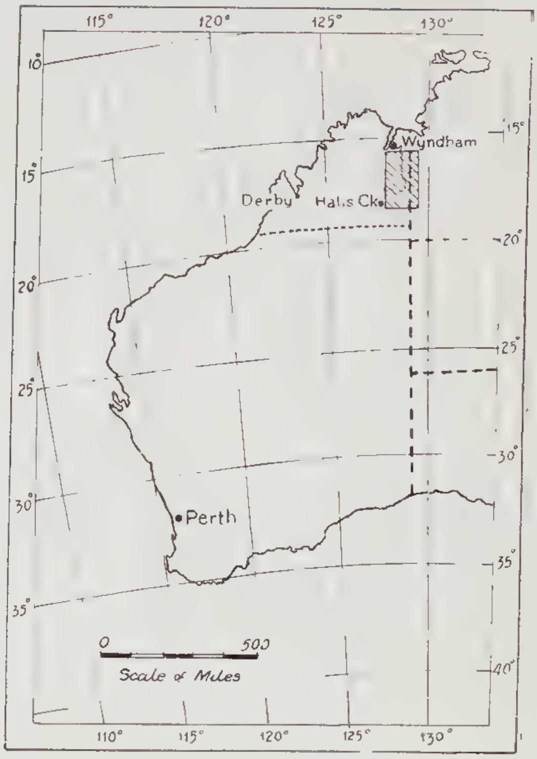

Fig. 1.—Locality Map showing the situation of the rocks under discussion (shaded area), and the position of Kimberley (north of the dotted line).

were made near Hall's Creek in about 1884, results were disappointing. There was no inducement, from the purely economic standpoint, for a systematic geological survey of the Division or of any part of it until, in about the year 1920, small amounts of mineral pitch and oil were found in Cambrian and in Permian rocks. These discoveries resulted in the detailed examination of a small area by Mahony (1922), to reconnaissances by Wade (1924) and Blatchford (1927), and finally to the extensive and detailed survey of a part of the West Kimberley by Wade (1936). From the time of the pioneer work of Hardman (1885), several geologists have also examined parts of the Division in order to determine its resources in gold or artesian water. They have thus had no reason to pay much attention to the basalt. All their reports, however, refer to the wide distribution of this rock, particularly in the eastern and northern parts of the Division.

During August and September, 1927, I was privileged to accompany the late Mr. T. Blatchford, Government Geologist of Western Australia, on a tour of inspection from Wyndham to Derby. The specimens described by Dr. Edwards were obtained during this journey, but I was not particularly interested in the basalt, and only made notes on it as a matter of course. I am much indebted to Mr. M. P. Durack for hospitality and guidance during the earlier parts of the trip, and to the Freney Kimberley Oil Co. and Mr. H. W. B. Talbot for a similar courtesy during its later part, also to Dr. Arthur Wade who read this part of the paper in MS. and made some valuable suggestions.

Although the conditions of travel under which the collection was made did not permit of a proper investigation of field occurrence, it is desirable that such an important petrological contribution as this should be prefaced by some attempt to describe the "geological setting."

Nearly all the specimens examined by Dr. Edwards were obtained in the Antrim natural region (Clarke, 1926) or Ordland (Jutson, 1934), which is topographically different from the adjoining North Kimberley natural region because of geological differences. The Antrim Region is made up

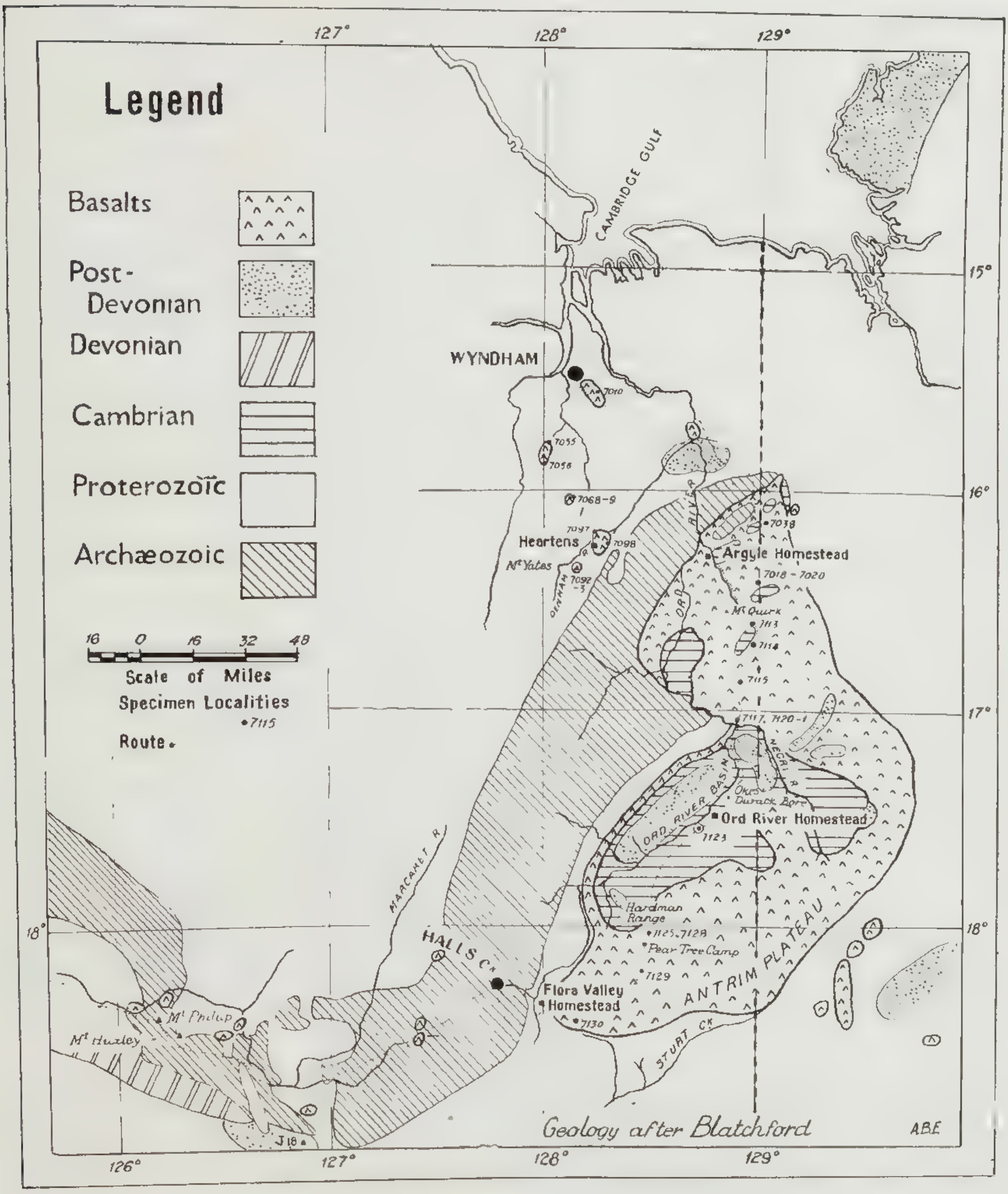

Fig. 2.—Geological Sketch Map of part of East Kimberley and the adjoining part of Northern Australia, showing the distribution of the basalts and the localities of the specimens described in the text.

mainly of basalts and Cambrian sediments which are in most places nearly horizontal; the North Kimberley has an eastern fringe of closely folded metamorphic Archaeozoic rocks overlain by more gently folded Proterozoic rocks, which are at most only slightly metamorphosed.

The sketch map (Fig. 2), which is almost altogether a copy of Blatchford's (1927) compilation from his own observations and those of previous observers, shows that in the East Kimberley "basalt" occurs:—

(a) in small patches associated with Pre-Cambrian rocks,

(b) in large areas associated with Cambrian rocks.

PUBLISHED OPINIONS REGARDING THE AGE OF THE BASALTS.

It is necessary in the first place to realise that views as to the age of the different formations in the Kimberley have changed, and particularly that the rocks marked "Proterozoic" on Figure 2 were considered to be Devonian by Logan Jack and others. This interpretation is found even in the title of Figure 48, page 29, of Maitland's "Summary of the Geology of Western Australia" (1919), but was disproved by Wade. Another cause of confusion in consulting the earlier reports is that, prior to Wade's surveys, the distinction between the Proterozoic rocks and the fossiliferous Cambrian strata had not been recognised. To avoid complication I have, where necessary, in summarising the opinions of others, changed their age-designations to those now generally accepted; such alterations are enclosed in square brackets [ ] and any explanations or comments are similarly indicated.

Hardman (1885) in his second report (on the country between longs. 126° 30′ and 129° 30′ and lats. 16° 40′ and 19° 00′) distinguished the two types of occurrence ("field groups") (a) and (b) mentioned above. He stated that the larger areas of basalt (field group (b)) underlie the [Cambrian] and overlie the [Proterozoic], both junctions being unconformable. He gave two measured thicknesses of this basalt as 900 feet and 1,100 feet. Regarding the [basalt] (indicated on Figure 2 of this paper) south of latitude 18° and between longitudes 126° and 127°, he said that there is no precise evidence as to age, but strong evidence [based apparently on lithological resemblance] that it belongs to the same igneous period as the extensive lava flows, and that the "belt of trap rock quarter to half-mile wide, traceable from Mt. Phillip to Mt. Huxley" is a dyke intrusive into quartzites and altered grits [which are now mapped as Proterozoic]. He mentioned other, similar cases (e.g., near J18 (126° 50′, 18° 55′) where a lenticular mass of amygdaloidal basalt, four or five miles long and one mile wide, has "burst up" through the [Proterozoic] rocks) and also noted that dykes and masses of basaltic rock invade the [Archaeozoic rocks], but that these instrusions and the [Archaeozoic] rocks are alike cut by quartz veins.

Woodward (1891) wrote of the "immense tracts" of country near the Border [between the Kimberley and North Australia] which are covered by basalts, and stated that basalts also occur as dykes in many places. [It would appear that he regarded the dykes and flows as essentially contemporaneous] but he did not express any opinion as to their geological age.

Jack (1906) dealt only with the basalt belonging to field group (b). He thought it likely that the basalt near Argyle Homestead is Kainozoic—much younger than the Antrim Plateau basalt. The Argyle basalt has, he wrote, "all the appearance of having simply levelled up a depression formed by the converging Bow and Ord Rivers." Between Rosewood Homestead and Mt. Quirk is a basalt puy, near which the lavas much

exceed in thickness the 300 feet which is the average for the Argyle basalts. On the other hand, the Antrim Plateau basalt is at least 660 feet thick.

Mahony (1922) described the structure of the Ord River Basin [a descriptive term later introduced by Wade (1924)]. The basalt in this basin is comformably overlain by Cambrian limestone, but its relation to the underlying [Proterozoic] hard grits and conglomerates, which also dip east, is not stated. [He estimated the basalt to be 4,000 feet thick—much more than any other observer made it.]

Wade (1924) described the Ord River Basin as being "completely surrounded and underlain by basalt," that in places encloses large masses of quartzite which stand out above the basalt plains. There is no discordance in dip between the basalt and the Cambrian sediments above it or the [Proterozoic] below. The Okes-Durack bore penetrated 408 feet of basalt, and did not reach the base of the formation. [From the particulars regarding "ashy" and vesicular layers, the 408 feet is made up of six flows.] Two periods of earth movement are recorded in the Ord River Basin—one post-Cambrian and one post-Permian. The latter was responsible for a good deal of thrust faulting. [Farquharson (1923) also concluded, from a petrological study of the basalt from near the junction of the Ord and Negri Rivers, that there is a shear zone in the basalt. If such movements occurred they may have obscured the relations of the limestone and basalt and caused Jack to think that the basalts in group (b) belong to two ages.] Wade saw no evidence for the puy [described by Jack]. The basalts south of Argyle Homestead gradually sink under the plain and the limestone appears again in solid beds [which seems to imply that the Argyle basalt underlies the Cambrian limestone as does the basalt in the Ord River Basin]. There is an extensive development of basalt 26 miles north of Argyle Homestead which has been involved in earth movements. He also stated that "14 miles south of Wyndham on the estuarine plain of the Ord," basalt forms "little rises all over the plain," and there occur "what appear to be basaltic cones." [It is not clear whether the basalt near Wyndham (spec. 7010, group 4)*, described as a dyke by Woodward (1891) and Maitland (1902) is part of this occurrence.] On Hicks Creek, north of Argyle Homestead, the basalt is "full of veins of quartz." [Quartz veins in basalt were seen by me only at Mt. Yates (Blatchford (1928)), and the feature does not seem to be recorded elsewhere for field group (b).]

Blatchford's (1927) report, though published later than Wade's, puts forward the results of field work in which these two geologists collaborated, and shows no material divergence from Wade's views as to the basalt.

Blatchford (1928) described the geological features noted in part of the journey which was mentioned at the beginning of this paper. Where the route traversed the North Kimberley natural region he considered that there was one suite of lavas and tuffs contemporaneous with the [Proterozoic] sediments and another of later date. The basalt near Argyle Homestead probably underlies the Cambrian limestones. No comparison of the ages of

* Referring to the number of the specimen in the collection of the Department of Geology, University of Western Australia, and to the group to which Dr. Edwards has assigned it.

the Argyle basalts with those in the North Kimberley natural region is made. Petrological notes by Dr. C. O. G. Larcombe are included in this report.

Summary.—Basalt in the East Kimberley has been described or mentioned by all geologists who have reported on the region; Jack and Wade alone express definite opinions as to the contemporaneity or otherwise of the occurrences which they saw, and those opinions are opposed.

FIELD OCCURRENCE OF MATERIAL EXAMINED.

Basic intrusions in Proterozoic rocks.—Regarding these, which comprise nearly all of field group (a), my field observations were confined to a small area in the North Kimberley, and are contained in Blatchford's report (1928). Of my specimens, the only ones fit for detailed examination are from intrusions in supposed Nullagine (Proterozoic) rocks. The specimens are 7068 and 7069 (group 7) and 7056 (group 1). It is particularly unfortunate that specimens 7092 and 7093, from Mt. Yates, which is a plug invading Proterozoic rocks (Blatchford, 1928, p. 13 and fig. 10), are too weathered to be any use.

Cambrian basalt outcropping in the Negri River.—In the Negri River, about 1½ miles above its junction with the Ord is the section mentioned by Blatchford (1927, p. 42 and fig. 37). The low cliff is composed from above downwards of about 30 feet of the "basal" Cambrian limestone (Blatchford, 1927 p. 15 and description of fig. 37); below this is about five feet of sandstone, which in places wedges out; the next bed (probably either a volcanic breccia or a flow) is much decomposed and passes down into a massive basalt (specs. 7117, 7120, and 7121 (group 3)), with very numerous amygdales most of which are siliceous. Impsonite occurs in vesicles and cracks in the more "solid" lower part of the basalt (Farquharson, 1923, p. 11).

Specimens were taken from two other localities in which basalt, apparently in the same stratigraphic position as the basalt in the Negri River, is exposed:—

(a) In a creek which is crossed by the Wyndham-Hall's Creek track ten miles south of Hardman Range. Here solid basalt (spec. 7125, group 4) is overlain by bedded rocks—apparently tuffs—above which is limestone about 30 feet thick, lithologically resembling the limestone which occurs at the east end of Hardman Range and which contains the Cambrian fossil *Biconulites hardmani* (Spath, 1936) formerly known as *Salterella.*

(b) At Pear Tree Camp flow-basalt (probably spec. 7128, but the label was lost in transit from the field) is overlain by agglomerate and by well-bedded tuff containing calcareous bands. The uppermost rock seen is a limestone, lithologically like the "Salterella" limsetone. If the limestone represents approximately the same stratigraphical horizon as that of the limestone in the Negri River near its junction with the Ord, and if the basalt is, as mapped by Blatchford and Wade, continuous with that in the Negri, then limestone and basalt should be conformable near Pear Tree Camp, but the impression is that the limestone overlies the basalt uncomformably.

Basalt forming much of Antrim Plateau and of Plains near Argyle Homestead.—Hearten's Homestead (long. 128°15′, lat. 16°18′) is in the North Kimberley natural region, with Pre-Cambrian rocks to the east and

west. Round it is a small plain underlain by basalt (specs. 7097 and 7098, group 2). The occurrence is mentioned here, because, although 35 miles east of Argyle Homestead it may be a survival of a once wider extension of the Argyle basalts next to be described.

Figure 3 gives one possible interpretation of the geology within a few miles of Argyle Homestead*, from which it is evident that, in my opinion, the Argyle basalts are younger than the Cambrian limestones and other sediments, and overlie them unconformably. However, this is only an opinion.

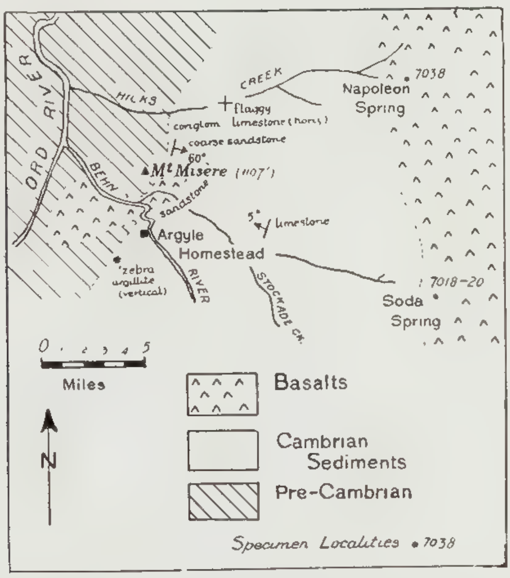

Fig. 3.—Geological Sketch Map of the country near Argyle Homestead, East Kimberley.

Careful geological mapping of the area is necessary, and such a survey would not be easy because outcrops are poor, and relief and dips are both low, except near Mt. Misère. Farther south in this area of "Argyle basalt" there are several cuesta-like hills surrounding and including Mt. Quirk. They are, judging from information from Mr. M. P. Durack and from the geological maps of Wade and others, composed of basalt, which, the topography suggests, may be in the form of a number of flows dipping gently away from the neighbourhood of Mt. Quirk. These basalt flows are at a distinctly higher level than the limestone "walls" described by Wade as having basalt both to the east and to the west. It appeared to me that the limestone of these "walls" is dipping in different directions at low angles; if this is so, the "walls" might be interpreted as the highest part of a land surface, the rest of which has been covered by basalt flows. No definite fossils have been reported from the limestones of this locality, but Wade considered them to be Cambrian, and lithologically they resemble the "Salterella" limestones to the south and to the north. Again, about five miles north of the Negri River it was noticeable that for two or three miles to the east of the Wyndham-Hall's Creek track are flat-topped hills, seemingly composed of horizontal flows of basalt, east of which is a large expanse of limestone country which is clearly at a lower level than the basalt.

*Specimens 7018-7020 and 7115, group 1, 7038 and 7113, group 3, 7114, group 4, were obtained either from this area or from its southern extension. (See Fig. 2.)

Six or seven miles south of Pear Tree Camp, where, as already stated, basalt which seems best assigned to the Negri group occurs, the track rises onto the Antrim Plateau; the difference in level between Pear Tree Camp and the Plateau is about 350 feet by aneroid readings. The basalt (spec. 7129, group 6) which outcrops on the Plateau appears much less weathered than that at Pear Tree Camp, and, judging by the topography, should overlie the Cambrian limestone, not underlie it as does the basalt in the Negri River.

The basalt on the Antrim Plateau seems to be but a thin layer, for, in a gully on the edge of the Plateau, about seven miles S.E. of Flora Valley Homestead, 15 feet of spheroidally weathered basalt (spec. 7130, group 3) overlies conglomerate containing boulders of granite, sandstone, and quartz. In several places on the Plateau, no basalt is seen, and the ground is strewn with water-worn pebbles and boulders of quartz and granite. This seems to indicate that erosion has removed the basalt entirely in some places and exposed the underlying sediments.

— —

CONCLUSIONS AS TO AGE RELATIONS.

Hurried field observations suggest that field group (a) consists mainly, if not entirely, of intrusions into Proterozoic rocks and that the large areas of basalt (field group (b)) represent two periods of vulcanism, one (of which the outcrops in the Negri River are typical) being Cambrian, the other (which gave the basalt found on the Antrim Plateau and near Argyle Homestead) being younger. This latter suggestion is at variance with the conclusions of others whose observations were more extensive than mine: Jack thought the Antrim and Argyle basalts to be of different ages, Wade and others inclined to the view that all the basalts of field group (b) are contemporaneous. Dr. Edwards informs me that, from the petrologist's point of view, there is no suggestion that basalts of two ages are represented—rather the reverse.

The following tabular comparison of field and petrological classification shows that, at any rate until much more field work has been done, the suggestion that the East Kimberley basalts are anything but a single series may be disregarded.

—		Field Classification.		
		Field Group (*a*).	Field Group (*b*).	
			Cambrian.	Post-Cambrian.
Petrological Classification	Group 1 ...	7056	...	7018–20, 7115
	Group 2 ...	7092, 7093	7128	7097, 7098
	Group 3 ...	...	7117, 7120, 7121	7038, 7113, 7130
	Group 4 ...	7010	7125	7114
	Group 6* ...	...	...	7129
	Group 7 ...	7069	...	...

* Group 5 is not represented in specimens from the Kimberley examined up to date.

II. PETROLOGY.

By A. B. Edwards, University of Melbourne.

INTRODUCTION.

The following notes are intended to supplement our meagre knowledge of the petrology of the East Kimberley basalts. They are based on the examination of a small collection of East Kimberley basalts, which was made during a reconnaissance trip by Professor E. de C. Clarke, who kindly placed the specimens at my disposal. The localities from which the specimens come are shown in the accompanying sketch map (Fig. 2). The examination was carried out in the Geology Department of the University of Melbourne by the kind permission of Professor Skeats. Of the six new chemical analyses submitted, five were made by the author, and the sixth by Mr. R. W. Fletcher in the Government Chemical Laboratory at Perth, under the direction of Dr. E. S. Simpson, by whose permission it is reproduced here. In addition, two specimens from the North-West Land Division and from North Australia respectively, which seem to belong to the same assemblage, are described.

PETROLOGY.

Several of the specimens in the collection (Nos. 7092, 7093, 7123, and 7128*) have been extensively altered, and the original material of the rock is largely replaced by limonite, and quartz in veins and stringers. Only the general appearance of a basaltic texture is preserved in these specimens, and in (7092, 7093) the outlines of plagioclase phenocrysts about 1 mm. long can be made out. It is unfortunate that these particular specimens should be so altered, since they are from a plug clearly intrusive into Nullagine quartzites at Mount Yates, on the Denham River (lat. 16° 20′, long. 128° 05′), the most definite evidence of intrusion that Professor Clarke saw during his journey.

The remainder, however, are sufficiently fresh for their mineral composition to be determined in some degree. All but one specimen (7192) are extremely fine-grained, and there is a general similarity about them. Despite this it has proved possible to classify them into several distinct, though perhaps gradational, groups. Chemical analyses have been made of the most typical rock in each group.

1. *Olivine-basalts.*
   - (7056) about 6 miles south of Fish Pool (lat. 15° 50′, long. 128°), underlain by red shale.
   - (7018) about 1 mile east of "Soda Spring" (east of the Argyle Homestead). This rock comprises the bulk of the hills about here.
   - (7019) same locality as (7018).
   - (7020) same locality as (7018).
   - (7115) about 40 miles south of the Argyle Homestead, on the track to Hall's Creek (lat. 16° 45′, long. 128° 58′).

These are extremely fine-grained aphanitic basalts, consisting of numerous small microphenocrysts of olivine (0.3 mm. across) and clots of equally small felspar crystals, set in a ground mass of plagioclase laths, augite and iron ore. The olivine is nearly always completely altered to serpentine, with

* Numbers thus (7128) refer to specimens in the rock collection of the Geology Department of the University of Western Australia.

a rim of iron oxide, while the felspar phenocrysts are saussuritized. The groundmass plagioclase has a maximum extinction angle of 25° in the symmetrical zone, corresponding to a composition Ab$_{55}$. The pyroxene, which is the least altered mineral, is colourless to greenish-brown, biaxial, positive, and has an optic axial angle (2V) greater than 45°, so that it is probably diopsidic. The iron ores form small shreds and needles scattered sparsely through the rock, and sometimes enclosed in augite grains. In (7020) patches of greenish chlorite are developed, while in (7018) and (7019) the groundmass consists of plagioclase laths in a glassy base. The glass, which was iron-rich, is now reddish-brown through the alteration of the iron oxide trichytes and dust to limonite.

A chemical analysis of (7056) is given in Table I, No. 1, and shows that these rocks resemble in chemical composition certain of the Tertiary Newer Volcanic olivine-basalts of Victoria (Table I, A). Like them it is relatively rich in SiO_2, being only slightly under-saturated with respect to silica.

TABLE I.

	Analysis. 1.	Analysis. A.
SiO_2	50·00	49·86
Al_2O_3	15·13	14·35
Fe_2O_3	3·06	4·21
FeO	6·07	7·02
MgO	8·33	8·25
CaO	9·10	8·45
Na_2O	2·59	2·80
K_2O	1·81	1·23
H_2O+	0·91	...
H_2O-	0·50	...
CO_2	0·20	0·04
TiO_2	1·25	1·62
P_2O_5	0·55	0·38
MnO	0·17	0·18
	99·67	

	Norms. 1.	Norms. A.
Q	...	1·81
Or	10·69	7·13
Ab	21·92	23·18
An	24·32	26·95
Ne	...	0·30
di	13·97	12·69
hy	15·52	13·72
ol	3·83	5·88
mg	4·42	5·17
hm	...	0·22
il	2·38	3·08
ap	0·66	0·45
cal	0·46	0·08

1. Olivine-basalt (7056), about 6 miles south of Fish Pool (lat. 15°50′, long. 128°), East Kimberley. *Analyst*—A. B. Edwards.

A. Average Footscray basalt (16 analyses), Victoria. (A. B. Edwards, *Quart. Journ. Geol. Soc. Lond.*, **xciv.**, p. 809, 1938. Note.—Norms averaged and not recalculated, in order to show how these rocks border between over- and under-saturation).

2. *Felspar-basalts.*

(7097), 2 miles north-west of Hearten's Homestead (lat. 16°16′, long 128°15′). This basalt makes up the bulk of the low country near the creek on which the homestead stands.

(7097, a), same locality.

(7098), 2 miles east of Hearten's Homestead, probably underlying the sandstones and conglomerates of "Conglomerate Range."

The distinctive feature of these three specimens is the presence in them of clots of plagioclase crystals, the clots being as large as 1 cm. in diameter. They are composed of prismatic crystals about 1 to 2 mm. long, which show zoning and lamellar twinning, with a maximum extinction angle of 30° in the symmetrical zone, so that their composition is about Ab$_{45}$. The extinction angle is frequently masked by the alteration of the felspar to saussurite, sometimes accompanied by epidote.

The clots are set in a fine-grained intergranular groundmass of felspar, pyroxene, iron ore, and a little devitrified green glass. The groundmass felspar is generally lath-shaped, and is somewhat saussuritized plagioclase of composition about Ab_{45-50}. The pyroxene is colourless when fresh, but is often altered to a fibrous greenish chlorite. It is usually granular, but the grains are too small for their optical character to be determined. They show extinction angles as high as 40°, so that they are probably relatively lime-rich. The iron ores are coarse-grained, with a tendency to square cross-sections, indicating magnetite. They approach the size of microphenocrysts, compared to the individuals of the groundmass.

(7097,a) appears to be a chilled phase of (7097). The felspar phenocrysts in it occur as individuals rather than as clots, and the groundmass is much more glassy. The iron ores occur as trichytes throughout the glass, and have been partially altered to limonite, so that the rock appears brown even in thin section. Secondary silicification has accompanied the limonitization, quartz appearing as stringers across the section. There is some resemblance between this specimen and the specimens from Mt. Yates (7092, 7093). (7128), probably from near Pear Tree Camp, 11 miles south of the Hardman Range might also be of this type.

A chemical analysis of (7098), (Table II. No. 1), reflects the general characters of the rock in its high lime and alumina contents. The low MgO corresponds with the absence of olivine. The analysis resembles in many respects that of a porphyritic felspar basalt from the Tertiary Newer Volcanic series of Victoria, occurring at Rocky Range, Lancefield (Table II, A).

TABLE II.

	Analyses. 1.	Analyses. A.		Norms. 1.	Norms. A.
SiO_2	51·80	48·49	Q	2·58	...
Al_2O_3	18·14	18·65			
Fe_2O_3	2·45	4·77	Or	11·19	10·51
FeO	6·61	7·07	Ab	23·01	29·52
MgO	3·98	4·65	An	31·71	29·98
CaO	8·50	8·27			
Na_2O	2·72	3·49	di	7·26	5·83
K_2O	1·89	1·79	hy	15·36	3·94
H_2O+	1·04	0·28	ol	...	8·60
H_2O-	1·05	0·60			
CO_2	0·05	*nil*	mg	3·53	6·93
TiO_2	0·75	1·37	il	1·43	3·85
P_2O_5	0·41	0·60	ap	1·00	1·42
MnO	0·08	0·15	cal	0·11	...
BaO	...	0·01			
	99·47	100·19			

1. Felspar-basalt (7098), 2 miles east of Hearten's Homestead (lat. 16°16′, long. 128°15′), East Kimberley.

A. Porphyritic-andesine-basalt, E. slope of N. point of eruption, Rocky Range, Parish of Lancefield, Victoria. (A. B. Edwards, *Quart. Journ. Geol. Soc. Lond.*, **xciv.**, 1938, Table V., No. 12. Note.—Fe_2O_3, 2.77, should read 4.77).

The Victorian rock is distinctly under-saturated in SiO_2, however, while (7098) shows a slight excess of SiO_2. The Victorian rock is also richer in MgO and in Na_2O, which resides mainly in the groundmass felspar and glass, since a partial analysis of the felspar phenocrysts shows them to have a composition about $Or_5\ Ab_{44}\ An_{51}$. The other type of rock which (7098) resembles in some respects is the Bunbury tholeiite, but this is distinctly poorer in alumina and rather richer in lime (Edwards, 1938).

3. *Aphyric basalts (Argyle Type).*

(7120), Negri River, about 1 mile above its junction with the Ord River, and from near the upper surface of the basalt, *i.e.* close to its contact with the adjacent Cambrian limestone.

(7117), same locality as (7120).

(7121), same locality as (7120).

(7113), Behn Creek, about 23 miles south of the Argyle Homestead, on the track to Hall's Creek (lat. 16°32′, long. 128°58′).

(7038), Napoleon Spring, 13 miles north-east of the Argyle Homestead.

(7130), about 8 miles east-south-east of Flora Valley Homestead, on the track to Hall's Creek. Basalt from the western edge of the Antrim Plateau.

This variety of basalt appears to be prominent in the vicinity of Argyle Downs, while its occurrence on the western edge of the Antrim Plateau suggests that it may be widespread. At the Negri River locality (7120) it definitely underlies Cambrian limestone. Despite its distinctive appearance in thin section, it is difficult to give it a suitable descriptive name on account of its fine-grained aphyric texture. It is suggested, therefore, that it may be distinguished by a local name as the *Argyle Type*.

The analysed specimen (7120), from the Negri River locality, is a fine-grained rock composed of stumpy laths of plagioclase (0.2 mm. x 0.05 mm.) which sometimes occur in clusters, together with smaller granules and prisms of colourless pyroxene, which is sometimes greenish from partial alteration to chlorite, coarse, irregularly rectangular areas of magnetite (0.2 mm. x 0.2 mm.) fringed with iron stains, and intersertal areas of light brown glass and apple-green material of chloritic appearance. The amount of felspar about equals the amount of pyroxene and glass. The laths show a maximum extinction angle in the symmetrical zone of about 30°, corresponding to a composition of Ab_{45}. In view of the relatively low CaO content and high Na_2O content of the analysis (Table III., No. 1), the brown glass must be largely felspathic, with a high soda content. The pyroxene has a low double refraction, and an extinction angle of about 40° on prism faces. It appears to be biaxial, positive, with 2V greater than 45°, but most grains are too small for determination. Small circular areas of fibrous zeolite, of low double refraction, occur occasionally within patches of the green glass.

(7117) is identical with (7120), except that the plagioclase is partially saussuritized, and (7038) differs only in the presence of infrequent microphenocrysts of altered plagioclase 1 to 2 mm. in length. The groundmass plagioclase has a composition about Ab_{50}, and one or two pyroxene grains showed acute bisectrix figures with 2V greater than 45°, indicating that it is lime-rich or augitic. (7113) from Behn Creek is generally similar, but the pyroxene is completely unaltered, and the amount of glass is very small. The plagioclase appears to be slightly more basic than in (7120).

(7130) from the western edge of the Antrim Plateau, differs from (7120) in that the iron ore is present in smaller but more numerous crystals, mostly in the brown glass. Considerable calcite occurs in small patches throughout the specimen, and the areas of green glass are associated with a little interstitial quartz (apparently primary), which is accompanied by oc-

casional small crystals of hornblende, pleochroic from straw yellow to greenish brown. This rock appears to be intermediate between the Argyle basalts, as represented by (7120), and the typical quartz-basalts described below.

4. *Quartz-basalts.*

(7125), from 9 miles south of the Hardman Range, on the track to Hall's Creek, near J. 32.

(7114), from "Sugar Spring," on the track from the Argyle Homestead to Hall's Creek (lat. 16°37′, long. 128°58′). This basalt is the general rock about here.

(7010), from "The Seven Mile," near Wyndham, on the road to the Argyle and Ord River Stations.

(7125), which is the analysed specimen (Table III., No. 2), contains numerous microphenocrysts of pyroxene, frequently with prismatic outlines, and about 0.3 mm. long. They are colourless to greenish grey and frequently cluster around relatively coarse, squarish grains of iron ore (0.3 mm. diameter). The pyroxenes in these clusters are stained with iron oxide along cleavages and cracks. The more idiomorphic crystals occur separate from the iron ore grains. Two types of pyroxene appear to be present. A number of crystals are biaxial, positive and have 2V larger than 45°, and an extinction angle of 35°-40°, so that they are lime-rich augites. Occasional crystals, however, appear to be almost uniaxial, so that some proportion of pigeonite accompanies the augite.

TABLE III.

	1.	2.	3.	4.	5.
SiO_2	53·95	54·40	52·58	52·67	50·50
Al_2O_3	15·98	14·34	10·56	14·34	14·25
Fe_2O_3	2·99	8·60	7·10	2·37	0·58
FeO	8·49	5·32	9·12	6·95	11·36
MgO	3·95	3·44	3·62	7·32	5·01
CaO	5·35	7·25	5·94	6·99	10·15
Na_2O	3·10	2·27	3·53	3·20	2·58
K_2O	2·00	1·95	2·80	1·92	1·39
H_2O + ...	1·25	0·34	1·33	1·99	0·35
H_2O —	0·65	0·56	0·56	0·38	0·62
CO_2	tr.	0·20	*Nil*	0·06	1·83
TiO_2	1·00	1·25	2·62	1·02	1·22
P_2O_5	0·68	0·30	n.d.	0·09	0·05
MnO	0·17	0·21	0·42	0·39	0·28
FeS_2	...	...	*Nil*	0·09	...
	99·56	100·43	100·18	99·78	100·13

NORMS.

	1.	2.	3.	4.	5.
Q	6·65	15·70	5·39	...	0·73
Or	11·80	11·52	16·55	11·35	8·24
Ab	26·22	19·19	29·88	27·05	21·81
An	23·80	25·98	4·73	19·15	23·70
di	0·39	4·89	19·84	11·60	12·20
hy	21·43	7·23	6·59	22·43	25·26
ol	...	...	...	...	...
mg	4·40	12·47	10·30	3·34	0·87
il	2·83	2·41	4·98	1·94	2·33
ap	0·80	0·34	...	0·03	0·06
cal	...	0·46	...	0·14	4·16

1. Argyle basalt (7120), Negri River, about 1 mile above its junction with the Ord River, East Kimberley. *Analyst*—A. B. Edwards.
2. Quartz-basalt (7125), 9 miles south of the Hardman Range, on the track to Hall's Creek. *Analyst*—A. B. Edwards.
3. Basalt (cf. 7010), from well at the 6-mile, south-east of Wyndham, Kimberley District. *Analyst* C. G. Gibson. (*Bull. G.S.W.A.*, 67, p. 22, No. 3779.)
4. Sub-ophitic basalt (7129), Flora Valley Station, about seven miles south of Pear Tree Camp, and 18 miles south of the Hardman Range, on the track to Hall's Creek. *Analyst*—R. W. Fletcher.
5. Aphanitic basalt (7069), hills west of flat at Martin's silver-lead mine (lat. 16°21′, long. 128°)—part of a large intrusion. *Analyst*—A. B. Edwards.

These small microphenocrysts of pyroxene and iron ore are set in a groundmass of plagioclase laths, granular to prismatic pyroxene, a little intersertal felspathic glass with a brownish tinge, a minor quantity of iron ore of late crystallization, and interstitial patches of relatively coarse-grained quartz. The quartz is usually accompanied by small sub-idiomorphic prisms of hornblende, which is pleochroic from straw yellow to greenish brown, and has an extinction angle of about 20° on the prismatic cleavage. The hornblende prisms occur between quartz grains and around the margins of the quartz areas. They are sometimes moulded on the coarser iron ore crystals, and on the pyroxene microphenocrysts, and occasionally appear to be intergrown with laths of plagioclase. There seems little doubt that the quartz and hornblende are primary minerals, representing the final residuum of the lava from which these rocks were derived. The groundmass pyroxene is colourless when fresh, but is largely altered to a fibrous green chloritic material. The grains are too small for their optical properties to be determined, but may be assumed to be pigeonite, in view of the composition of the microphenocrysts. The felspar is plagioclase of a composition about Ab_{45}. The groundmass iron ore is in small grains and rods, and is sometimes moulded on the pyroxene.

(7114), from "Sugar Spring," carries occasional phenocrysts of partially saussuritized plagioclase which shows zoning. The cores of these crystals show extinction angles of about 30° in sections parallel to (010), while the rims extinguish at 15°. These values correspond to compositions of Ab_{30} for the core and Ab_{50} for the margin. The groundmass felspar has about the same composition as the margins of the microphenocrysts. The pyroxene phenocrysts appear to be lime-rich augites, in that a few crystals gave positive acute bisectrix figures with 2V greater than 45°. The iron oxides are coarsely rectangular and sparsely distributed, and a few prisms of hornblende accompany the small areas of interstitial quartz.

In (7010), from "The Seven Mile," near Wyndham, the pyroxene microphenocrysts are fewer but larger (1 mm. long) and sub-idiomorphic. They show positive acute bisectrix figures with 2V greater than 45°. The early formed iron ore crystals are not as large as those in (7125), and the pyroxene microphenocrysts, about 1 mm. long, are also present. They are relatively unaltered, with coarse lamellar twinning, and appear to be labradorite (Ab_{45}). Hornblende prisms accompany the areas of interstitial quartz, as in (7125), and here and there there are serpentine pseudomorphs, apparently after microphenocrysts of olivine. It seemed possible that this specimen might correspond to an analysed specimen (G.S.W.A. 3779) from a well six miles south-east of Wyndham (Table III, No. 3), but the analysis is scarcely comparable with that of (7125) (Table III, No. 2). The high FeO in both suggests that they have both undergone partial replacement

by limonite, though it may be partly a reflection of the numerous coarse crystals of magnetite. The very low Al_2O_3 of (G.S.W.A. 3779) is perhaps attributable to leaching out of alumina during this process. Even so, there is no agreement as to soda, potash and lime content, and the amounts of these oxides present are scarcely reconcilable with the compositions of the felspars in (7010). The analysis of (G.S.W.A. 3779) compares much more closely in these respects with that of the Argyle basalt (Table III, No. 1).

5. *Pyroxene-basalt.*

(7174), Kelly's Yards, Victoria River, Northern Territory, at the junction of the Dry River, Victoria and Western Australian stock routes. The rock is intrusive into limestone, but is also overlain by sandstone and limestone. (Collected by H. A. Ellis.)

This rock is composed of abundant phenocrysts of pyroxene with occasional large laths of altered plagioclase, in a much altered intersertal groundmass of altered pyroxene, saussuritized laths of plagioclase, iron ore, and abundant devitrified green glass. The pyroxene phenocrysts are squarish to rectangular crystals, about 1 mm. to 1.5 mm. across, and often slightly corroded. Sometimes they occur in clots. They are colourless, biaxial, positive, with 2V greater than 45°, and a moderate birefringence, so that they are presumably augite. They are generally fringed with fibrous greenish-brown alteration product, and occasionally enclose small crystals of iron-stained serpentine, pseudomorphous after olivine. Similar pseudomorphs occur in the groundmass. They resemble in size and appearance the olivine crystals in the olivine-basalts described above. The felspar phenocrysts were originally plagioclase in the form of laths about 2 mm. x 0.5 mm., but are too altered to saussurite for their original composition to be determined. Coarse, more or less square crystals of iron ore (0.2 mm. across) are also prominent against the altered groundmass.

6.—*Sub-ophitic basalt.*

(7129), Flora Valley Station, about seven miles south of Pear Tree Camp, and 18 miles south of the Hardman Range, on the track to Hall's Creek (lat. 18°07′, long. 128°25′).

The collection contains only one example of this variety of basalt, which is a relatively coarse-grained, sub-ophitic basalt consisting of laths of plagioclase and prisms of pyroxene in a base of interstitial plagioclase and minor amounts of iron ore. By comparison with the other basalts of the collection it is decidedly coarse-grained. The plagioclase laths mostly give extinction angles of about 25°, corresponding to a composition Ab_{55}, but one or two have angles as high as 35° corresponding to Ab_{35}. The high Na_2O content of the analysis (Table III., No. 4) suggests that the interstitial felspar of the base, which occurs as plates, some with multiple twinning or untwinned, must be more sodic than these laths. The pyroxene prisms are frequently partially altered to a fibrous yellow-green chlorite. When fresh they have a colourless core and a brownish to violet rim. They are biaxial and show a positive acute bisectrix figure, with 2V greater than 45°, so that they are probably augites. Their sub-ophitic intergrowth with the plagioclase laths sometimes produces a maltese-cross arrangement of the crystals. Occasional patches of bright green serpentinous material appear to be pseudomorphous after corroded olivine crystals.

7.—Aphanitic basalt.

(7069), from the hills west of the flat at Martin's Silver-lead mine (lat. 16° 21′, long. 128°). Part of a large intrusion.

This specimen is an extremely fine-grained rock of basaltic appearance, but it so much altered that little can be made out concerning its texture, except that it originally consisted of microlites or very small laths of plagioclase, minute granules of pyroxene, and particles of iron ore, possibly with some glassy base. An analysis (Table III., No. 5) confirms that it is of basaltic composition, on the border-line between saturation and undersaturation with respect to SiO_2, and in many respects comparable with the olivine-basalts described above. The high CO_2 content indicates the extensive alteration it has undergone. The analysis can be matched in some degree with analyses of some of the iddingsite-basalts of the Tertiary Newer Volcanic Series of Victoria (Edwards, 1938, b, Table V., Nos. 3, 4; Table VI., No. 2), but there are small discrepancies. From the notes by Professor Clarke which accompanied the specimens it seems probable that (7069) is the chilled margin of a gabbroic intrusion, represented by (7068), from the same locality. (7068) is a medium-grained gabbro consisting of allotriomorphic plates and laths of labradorite (Ab_{45}), grey to faintly violet pyroxene (2V greater than 45°), and abundant coarse iron ore grains (probably an intergrowth of ilmenite and magnetite). The iron ore appears to be the last mineral to crystallise, and is sometimes accompanied by small flakes of biotite. The pyroxene is somewhat chloritized.

A specimen (1785), from the Nullagine Series, two miles south-west of Nullagine, is closely comparable in appearance with this aphanitic basalt.

DISCUSSION.

The collection is too small to cover the whole range of basalt types and their differentiation products in the East Kimberley district, but the wide scatter of the localities from which the specimens were gathered make it probable that they are representative of some at least of the more common varieties. On this assumption it is possible to deduce the general petrological characteristics of this Cambrian basaltic area. The general resemblances between the types of basalt described above and their chemical similarities suggest that the East Kimberley basalts, as a whole, form a homogeneous petrographic province. No specimen in the collection is of a discordant type.

An outstanding feature of the collection is the relative scarcity of olivine in these rocks. Even in the olivine-basalt group, olivine is not the dominant mineral that it is, for example, in most of the Tertiary basalts of Victoria; and in the other East Kimberley rocks it is either rare or absent. This is in conformity with their chemical compositions. The analyses indicate that they are mostly saturated, or slightly oversaturated, with respect to SiO_2. The olivine-basalt group, which is the exception, is only slightly undersaturated, and, as has been indicated, these rocks closely resemble in chemical composition a widespread group of Victorian olivine-basalts whose composition borders between saturation and undersaturation. Whereas these Victorian basalts differentiated towards end-products more or less typical of undersaturated magma, the East Kimberley basalts have differentiated towards saturated types, such as the quartz-basalts.

In Table IV. the average composition of these East Kimberley basalts is compared with the average composition of basalts from several other regions. It will be seen that the East Kimberley rocks are intermediate between the typical undersaturated "olivine-basalt magmas" and the typical oversaturated "tholeiitic magmas" (Kennedy, 1933) or "plateau-basalt magmas" (Washington, 1922). The affinities of the East Kimberley suite are with the "tholeiitic magma type."

TABLE IV.

	1.	2.	3.	4.	5.	6.
SiO_2	45	50	52·2	50·5	50	51·3
Al_2O_3	15	15	14·5	14·8	13	13·9
FeO Fe_2O_3	13	11·5	11·2	11·5	13	13·1
MgO	8	8·5	5·0	6·0	5	5·5
CaO	9	8·5	7·3	10·9	10	9·8
Na_2O	2·5	3	2·9	2·9	2·8	2·8
K_2O	0·5	1·2	2·0	0·5	1·2	0·7

1. Olivine-basalt magma type (Hebridean Plateau Magma type). W. Q. Kennedy, *Summ. Prog. Geol. Surv. Gt. Brit.*, 1930, II., 66; *Amer. Journ. Sci.*, Ser. 5, **25**, 1933, 239.
2. Probable parent magma of Victorian Newer Volcanic Series. A. B. Edwards, *Quart. Journ. Geol. Soc. Lond.*, 94, 1938, 313.
3. Average East Kimberley basalt (7 analyses).
4. Average Tertiary tholeiite from south-western Western Australia. A. B. Edwards, *Journ. Roy. Soc. W.A.*, vol. **XXIV.**, 1937-38, p. 7.
5. Tholeiitic Magma Type (Non-porphyritic Central Magma type), W. Q. Kennedy (as above under 1).
6. Average Deccan basalt (16 analyses), G. W. Tyrrell and K. S. Sandford, *Proc. Roy. Soc. Edin.*, 53, 1933, III., 312.

It seems clear, as Barth (1936) contends, that we have no assurance of the existence of a uniform world-wide primary magma, and that while there are undoubtedly two main types of basaltic lava—an undersaturated one ("olivine-basalt magma type"), characterized by an alkaline, quartz-free residuum; and an oversaturated one ("tholeiitic magma type"), characterized by a quartzo-felspathic residuum—there are also primary magmas of all compositions intermediate between these two extremes. Barth deduces on theoretical grounds that basalts poorer in SiO_2 than a certain composition must differentiate to give an under-silicated residuum, while basalts richer in SiO_2 than a certain composition must differentiate to give a quartzose residuum. The course of differentiation followed by basalts intermediate between these two limiting compositions, e.g. the Footscray type of Victorian Newer Basalt, and the olivine-basalts of the East Kimberley suite, will depend partly on their composition—whether it veers towards undersaturation or oversaturation—and partly on the condition attending early crystallization, e.g., whether it gives rise to early olivine, which is not resorbed, and yet leaves the residual magma undersaturated, as in the Victorian province, or makes the residual magma oversaturated, as appears to have happened in the East Kimberley province.

CONCLUSIONS.

The Cambrian basalts of the East Kimberley district of Western Australia are in the main, fine-grained types, saturated with respect to SiO_2 and poor in olivine. They range from olivine-basalts to quartz-basalts, and

have distinct affinities with the tholeiitic—or plateau-basalts, although they appear to be derived from a magma on the border-line between undersaturation and oversaturation. If differentiates more acid than the quartz-basalts described above are found in these regions, they should be andesites.

They appear to form a single basaltic province, but the possibility must be kept in mind that they may comprise flows of two ages, one being Cambrian and the other somewhat younger.

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8.—THE OCCURRENCE OF XENOTIME IN WESTERN AUSTRALIA,

By

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In 1912 a few small dull yellow or pale brown octahedral crystals were detected during the examination of stream tin concentrates received at the Government Laboratory from Greenbushes. These proved to be xenotime, and this is the first recorded finding of the mineral in Australia. Since then the mineral has been found to occur at several places near Greenbushes, and also in the Central and Northern parts of the State, as a minor constituent of pegmatites, or in alluvial concentrates. The crystals are, with the exception of those from one locality, minute in size, and of a dull yellow or pale brown colour. Because of the minute size of the crystals and their common association with zircon a detailed description and an analysis was not made of them.

In composition xenotime is a rare earth phosphate, the rare earths being essentially of the yttrium group. The formula is YPO_4. Yttrium usually predominates, although some analyses show a large proportion of erbium.

Yinnietharra Xenotime.

At Yinnietharra in the Gascoyne district one detrital pebble 2 cm. in size was first found. This piece had a resinous lustre and showed imperfect cleavage. A larger piece has recently been recovered from the same locality. This mass measured 4½ x 3 x 2½ cm., and weighed 150 grams, which enabled a more complete description and an analysis of the mineral as occurring in this district to be made.

In appearance this specimen is pale olive green in colour with a vitreous lustre. The cleavage is nearly perfect in two directions and there is a fairly well defined parting. The surface is covered with a reddish-brown alteration product which penetrates the mass as a staining. In thin splinters the mineral appears greenish and translucent by reflected light. Examined under the microscope the fine powder is colourless and transparent by transmitted light, while the larger grains are yellowish brown in colour.

By coarse crushing and hand picking fresh portions of the mineral almost free from alteration products were selected for analysis. The specific gravity of this material was 4.55.

The analytical results obtained by the author are as follows:—

	%
*Y_2O_3 group	59·42
Ce_2O_3 + La, Di groups	·14
Fe_2O_3	1·19
Al_2O_3	*nil*
ThO_2	1·65
ZrO_2	·23
TiO_2	·01
SiO_2	1·76
UO_3	2·19
MnO	Tr.
CaO	*nil*
MgO	·16
PbO	·16
P_2O_5	33·38
As, Sb, Sn	*nil*
H_2O+	·29
H_2O-	·05
	100·63

* Y_2O_3 group, Mol. Wt. 249, calculated as Y_2O_3 46·03% ; Er_2O_3, etc. 13·39%.

The mineral was found to be difficult to decompose completely by fusion with alkali carbonates. It is not attacked by nitric or hydrochloric acids, but the fine powder is completely soluble in fuming sulphuric acid.

Of interest is the amount of uranium and thorium found to be present. The calculated radium content is .0063 grams per ton. Uranium bearing xenotime is also known to occur at Holleton.

XENOTIME IN THE SOUTH-WEST.

Holleton.—A prospector at Holleton while concentrating a biotitic albite pegmatite to determine if it contained gold, obtained a heavy yellow concentrate consisting mainly of xenotime. Several samples were examined. They yielded about 1% of concentrate consisting of 88% to 92% of xenotime, the rest being mainly zircon. During 1929, under the name of the "Radium Mine" this coarse pegmatite, which is on the west slope of Mt. Lookout, was worked for the mineral. The biotitic portions were found to carry up to 1% xenotime, but no richer material was located. Four samples examined gave the following results:—

	I.	II.	III.	IV.
Rock	Biotitic	Biotitic	Biotitic	Felspathic
Total concentrate (%) ...	·81	1·10	·90	·75
Xenotime (%)	·71	1·00	·83	Trace

The chief associated heavy minerals were zircon, ilmenite and epidote. A partial analysis of two concentrates was made to determine the possible amount of radium that might be expected to be present. The results of these are given below.

	(a)	(b)
Rock	Mainly biotite	Biotite, quartz, etc.
Concentrate (%)	·86	·62
Rare earths (%)	61·14	60·14
UO_3 (%)	·99	·91
Radium (grams per ton)	·0028	·0026

Analyst : D. G. Murray.

The xenotime occurred in minute yellow transparent and translucent octahedral crystals.

The other localities at which the mineral has been found in the South-West are as follows:—

Greenbushes.—(a) In a concentrate from Kelly's Flat consisting mainly of ilmenite and zircon; (b) a concentrate from Poverty Flat consisting mostly of ilmenite, zircon and kyanite. Both contained a few minute crystals of xenotime. These were dull yellow octahedral crystals, a few of the larger being 0.5 to 2.0 mm., in diameter.

Smithfield.—Small crystals of xenotime were found to be present in an alluvial concentrate which consisted of monazite, xenotime, gahnite, ilmenite, rutile and zircon. In another alluvial concentrate from the same district it was associated with ilmenite, cassiterite, magnetite and garnet.

Donnybrook.—A stream sand contained a little xenotime associated with ilmenite, rutile, zircon, kyanite and magnetite.

Lowden.—Two small greenish brown, translucent crystals were found here.

Westonia.—The concentrate from a microcline pegmatite was found to consist of a few small crystals of xenotime.

NORTH-WEST AND CENTRAL DISTRICTS.

Besides the previously described occurrence at Yinnietharra, xenotime has been found at Nullagine and Abydos in the North-West, and Niagara in the Central Division.

Nullagine.—On the south side of Grant's Flat, ½ mile from the town, xenotime has been found in alluvium as water worn lenticular pebbles 2 to 5 mm. in diameter. These pebbles are a dull yellow or brownish black colour.

Another sample from Nullagine, a sandy and gravelly concentrate, was also found to contain xenotime among the following heavy minerals: monazite, barite, limonite, tantalite, ilmenite, magnetite, chromite, rutile, zircon, cassiterite, pyrite and gold. A partial analysis of this concentrate gave the following results:—

	%
SiO_2	16·08
Fe_2O_3	31·43
$(TaNb)_2O_5$	4·72
P_2O_5	6·04
Ce_2O_3	3·51
Y_2O_3	5·30
ThO_2	·52
TiO_2	9·15
$BaSO_4$	10·44
Ign.	2·85
Al_2O_3, CaO, Alkalies, etc.	(9·96)
	100·00

Analyst: D. G. Murray.

Abydos.—A few small crystals were detected in a fine grained concentrate which consisted mostly of spessartite, with some monazite, cassiterite, tanteuxenite, haematite and limonite.

Niagara.—A few minute crystals were found in the concentrate from a pegmatite.

SUMMARY.

The localities known to the Government Laboratory in which the mineral xenotime has been found in Western Australia are given. The main occurrences are described in detail, including a recent analysis of the mineral from Yinnietharra.

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9.—A NOTE ON THE AGE RELATIONS OF THE BASIC PORPHYRITES AND ALBITE PORPHYRIES OF THE GOLDEN MILE, KALGOORLIE, WESTERN AUSTRALIA,

By

REX T. PRIDER, Ph.D., B.Sc., F.G.S.

Read 14th November, 1939; Published 16th August, 1940.

Since the publication in 1929 of F. L. Stillwell's bulletin on the "Geology and Ore Deposits of the Boulder Belt, Kalgoorlie" (2) no further note has been made regarding the time sequence of intrusion of the albite porphyries and the basic porphyrites. Stillwell says (2, p. 39) that "while the albite porphyry and the basic porphyrite are closely related rocks in form and occurrence the precise relationship in the time of the relative intrusion is obscure. No clear observation has been made of the intrusion of a basic porphyrite into an albite porphyry." He concludes, from a consideration of indirect evidence, that the basic porphyrites are probably slightly earlier intrusions than the more acid albite porphyries.

Thomson (3, p. 664) considered that there was a close magmatic relationship between the quartz dolerite series and the porphyry dykes and his conclusions are supported by Feldtmann (1, p. 87) and Stillwell (2, p. 60). Stillwell considers that the basic porphyrite and the albite porphyries are magmatically related and that the similarity between the chemical analyses of basic porphyrite and quartz dolerite indicates that they were derived from the same ultimate source. He quotes analyses (2, p. 60) in support of this statement, but from this table it will be seen that he is comparing analyses of rocks which have been metasomatised to a varying degree, one of the rocks containing 8.64% CO_2 whereas the others contain very little. In order to trace any magmatic relation between these rocks it is necessary to compare analyses of types which show the same degree of metasomatism, preferably from the same locality, but failing that, to compare analyses which have a similar CO_2 content. In the following table analyses of members of each of the main types (quartz dolerite greenstone, basic porphyrite and albite porphyry) which show a comparable degree of carbonatisation are set down (all of these analyses are quoted from Stillwell's bulletin):—

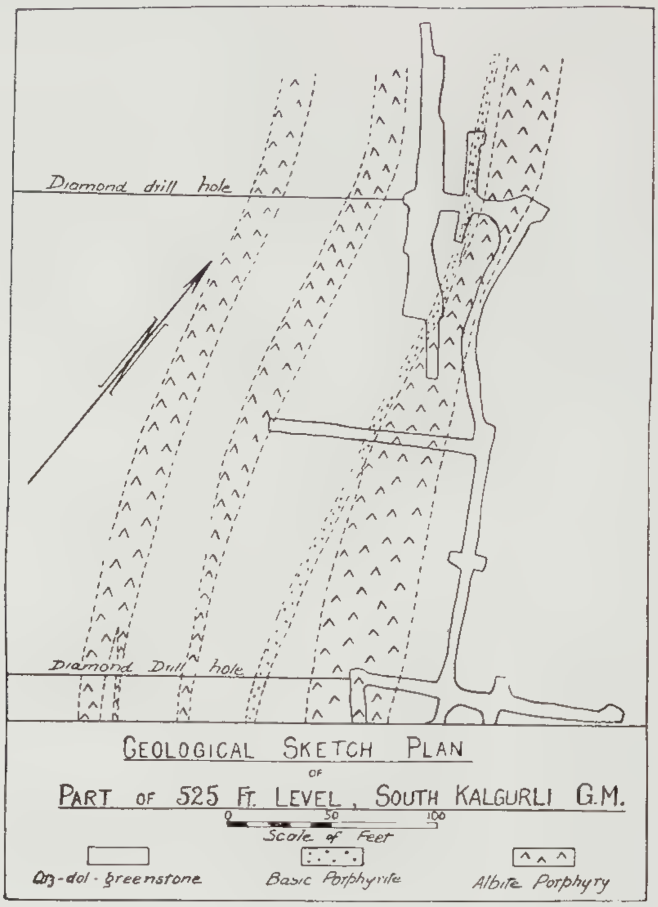
	1.	2.	3.
SiO_2	45·03	49·86	61·91
TiO_2	·64	·40	·47
Al_2O_3 ...	9·87	14·93	13·66
Fe_2O_3 ...	4·35	3·22	·81
FeO	11·58	4·34	2·69
MnO	Tr.	·15	·02
MgO	4·26	4·04	1·85
CaO	8·86	6·05	4·11
Na_2O	3·17	4·24	5·03
K_2O	·38	1·65	1·82
H_2O+ ...	1·83	1·40	·58
H_2O- ...	·11	·06	·02
P_2O_5	n.d.	·41	·16
CO_2	8·43	8·64	6·14
FeS_2	·24	·11	·09
Others ...	*Nil*	·10	*Nil*
	98·75	99·60	99·43

1. Quartz dolerite greenstone. (2, p. 27, analysis No. 2.)
2. Basic porphyrite. (2, p. 40, analysis No. 1.)
3. Albite porphyry. (2 p. 33, analysis No. 5.)

h 19/40

The serial chemical characters of the rocks quoted above point clearly to their comagmatic origin—if they represent successive differentiates of increasing acidity from the greenstone magma, then they would be expected to be intruded in the order:—(1) quartz dolerite, (2) basic porphyrite, (3) albite porphyry.

The author has made several observations on the relationship of the acid and basic dykes which appear to confirm the conclusions obtained indirectly by other observers.

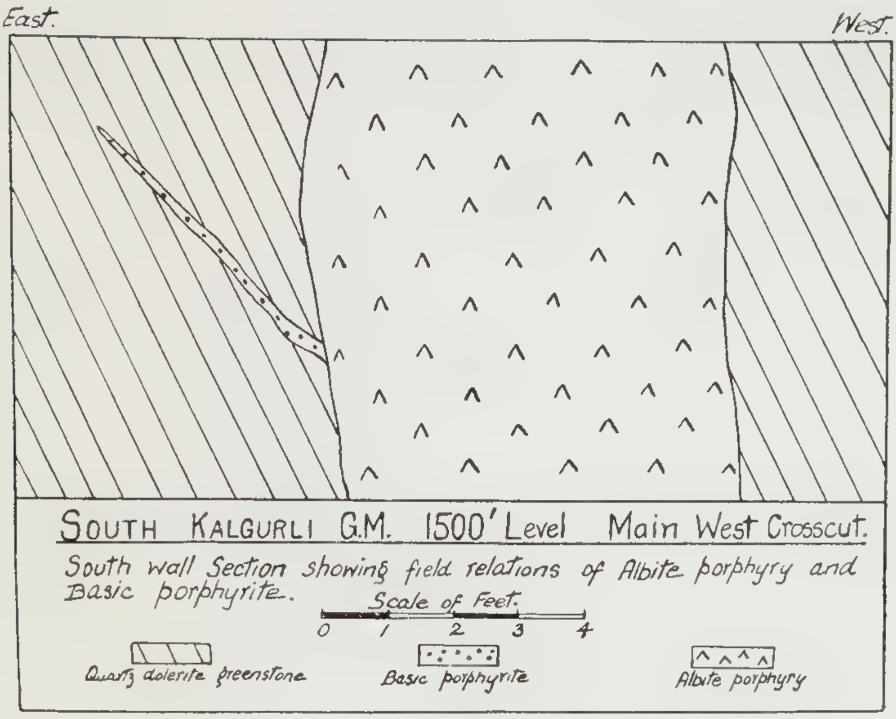


Text Figure 1.

Generally the long narrow hornblende porphyrite dykes run parallel to the wider, more irregular albite porphyry dykes. A typical occurrence is shown in the sketch plan of the north end of the South Kalgurli workings on the 525 ft. level (fig. 1). Here the two dykes are in contact for some considerable distance but do not intersect each other. On the level above (409 ft. level) the same conditions obtain except that the acid and basic dykes are separated by a selvage, one or two inches wide, of bleached quartz dolerite greenstone. The width of the basic porphyrite here is from five to six feet.

Where the basic dykes are more narrow they may be cut by the albite porphyry as shown in figure 2. The occurrence figured is almost at the western end of the main west crosscut at the 1,500 ft. level of the South Kalgurli mine near the South Kalgurli-Enterprise boundary. Here the basic dyke is only two or three inches wide but is well marked and ends abruptly against the larger albite porphyry dyke. The fact that the basic dyke lenses

out to the east side of the section seems to indicate that it was intruded from the west lower side of the section shown and has therefore been cut off by the intrusion of albite porphyry and this establishes their relative age. Unfortunately, the story is only half told by this section, as the lower half of



Text Figure 2.

the basic dyke is not visible but it may easily be on the west side below the floor of the crosscut, in which case it would appear to be older than the albite porphyry. This is, so far as I am aware, the only place where the relation of the two dyke rocks is visible.

The rarity with which the two types of intrusive intersect each other is probably due to the fact that the basic dykes, which are very fine grained and but little affected by shearing, have acted as a bar to the acid intrusions and only the very narrow basic dykes (as in figure 2) have been cut through by the later more acid series.

ACKNOWLEDGMENT.

The author wishes to thank Mr. F. G. Brinsden, General Manager of the South Kalgurli Cons., Ltd., for permission to publish this paper.

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10.—MARINE JURASSIC OF EAST INDIAN AFFINITIES AT BROOME, NORTH-WESTERN AUSTRALIA.

By Curt Teichert,

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Read 12th December, 1939; Published 28th August, 1940.

CONTENTS.

ABSTRACT.

Artesian bores at Broome, North-Western Australia, have disclosed the existence of a series of strata of Jurassic age at depths ranging probably from about 950 feet to at least 1,550 feet. The following fossils have been obtained from various depths between approximately 1,170 and 1,300 feet: ***Buchia subspitiensis*** (Krumbeck), ***Buchia subpallasi*** (Krumbeck), ***Belemnopsis* cf. *alfurica*** (Boehm), and ***Belemnopsis* cf. *incisa*** (Stolley). This assemblage seems to correspond most closely to that of the "Aucellen-Sandstein" of the island of Misool. The relationships of the Australian fauna to contemporaneous faunas of the Timor-East Celebes geosyncline, of the Himalayas (Spiti shales), and of New Zealand (Kawhia Harbour) are discussed and the fossils are described.

INTRODUCTION.

During Jurassic time Australia experienced a continental period with deposition of terrestrial and lacustrine sediments over wide areas in different parts of the country. Marginal parts, bordering the shield in Western Australia, were, however, affected by marine transgressions of which the one that has left its traces in the Geraldton district has been known for a long time. Spath has recently (1939) from a study of the ammonoid fauna of this transgression correlated the Geraldton strata with the *sauzei* zone of the European Bajocian but he states that the fauna is of a somewhat isolated character.

That this Bajocian transgression in Western Australia reached beyond the limits of the Geraldton district, where the main exposures of the strata occur, was indicated by me in 1940, when I described an occurrence of strata of presumably the same age from the Minilya River, North-West Basin, approximately 450 miles north of Geraldton. It is not unlikely that the Bajocian sea in Western Australia transgressed along an extensive belt, but that its

deposits are now either inaccessible or have been removed by erosion. In that paper the discovery was announced of Jurassic strata of different age in the northern part of the Westralian Geosyncline. The study of the fossils from these strata has now been completed and preliminary remarks on the fauna have already been published in another paper (Teichert 1939).

As early as 1919 Maitland (p. 41) mentioned the occurrence of belemnites in one of the Artesian bores (No. 2) at Broome, North-western Australia, at a depth of 1,300 feet below sea-level. From this he inferred the presence of strata of either Jurassic or Cretaceous age in this region. On later geological maps the area was shown as Jurassic, and Clapp discussed (1926, p. 1129) the possible extension of these strata into the Desert Basin. Since the appearance of Maitland's summary in 1919, additional bores, particularly No. 3, have brought to light more fossil specimens and it is now possible to determine the age of these fossiliferous strata below Broome and their palaeogeographic relationships.

During a visit to Broome in June, 1939, Mr. B. E. Bardwell kindly showed me a specimen of a belemnite which had been obtained from one of the artesian bores there. As this specimen was not related to any belemnites so far known from Western Australia, my interest was aroused and inquiries regarding further fossils from the bores were made. Mr. H. A. Ellis, Acting Government Geologist, and Mr. Crawford, who had been in charge of the boring operations, very kindly assisted in collecting the necessary information, and Mr. Ellis also placed at my disposal the specimens which are now kept in the collections of the Geological Survey of Western Australia. To all these gentlemen I wish to render my sincere thanks for their valuable help. The plate has been prepared by Mrs. Gertrude Teichert. I also wish to thank Professor E. de C. Clarke for careful reading and valuable criticism of the manuscript.

THE STRATA AND THEIR FAUNA.

Four artesian bores have been put down within the limits of the township of Broome, all of them starting at approximately the same height, not much above sea-level. Until a depth of round about 950 feet a series of sands or loosely cemented sandstones interbedded with a few conglomeratic layers was penetrated. Below this sandy series a layer of grey or dark blue shale was struck and shaly strata predominate below this level. The actual depths at which the first shale layer was struck are:—

963 feet in bore No. 1
920 feet in bore No. 2
960 feet in bore No. 3
935 feet in bore No. 4

It would appear, therefore, that the surface of the shale is slightly undulating. The thickness of this uppermost shale layer in bores No. 1 and 3 is 10 and 11 feet respectively and in both bores it is underlain by 3 feet of hard sandstone. This sandstone band seems to be missing in bore No. 4, and no accurate log is available for these levels in bore No. 2. The log of bore No. 3 is reproduced here in Table I as fairly representative for the section. Shales with occasional intercalations of greensand and limestone constitute most of the section below 960 feet.

Table I.

Log of Artesian Bore No. 3 at Broome.

Depth from surface Feet	
47	Red sandy loam getting lighter in colour.
102	Soft grey sandstone, hard in places.
112	Soft grey and yellow sandstone, hard in places.
143	Yellow sand.
200	Yellow sand.
218	Yellow sand.
246	Coarse grey sand with hard knobs.
285	Soft grey sandstone.
300	Soft brown sandstone.
316	Brown sandstone.
320	Coarse brown sand.
411	Very soft grey sandstone.
442	Very soft grey sandstone.
454	Coarse brown sand with hard knobs.
470	Very soft grey sandstone.
480	Light pink sand.
527	Light pink sand with grey bands.
534	Grey sand.
536	Coarse grey sand with clay bands.
548	Red sand with ironstone nodules.
581	Grey drift sand.
623	White drift sand.
640	White drift sand with water worn quartz pebbles.
741	Coarse white sand.
743	Coarse sand with water worn pebbles.
763	Coarse white sand.
813	Soft red sand.
814	Gravel bed.
849	Soft yellow sand.
856	Soft grey sandstone.
857	Hard grey sandstone.
867	Soft grey sandstone.
868	Hard grey sandstone.
909	Soft grey sandstone.
914	Soft grey sandstone.
938	Grey sandstone.
939	Hard sandstone.
950	Soft grey sandstone.
953	Hard sandstone.
960	Soft grey sandstone.
971	Grey shale.
972	Very hard band.
979	Soft grey shale.
1001	Fine sandy shale.
1040	Puggy shale, very soft in places.
1042	Puggy shale.
1043	Very hard band.
1056	Puggy shale with pyrites.

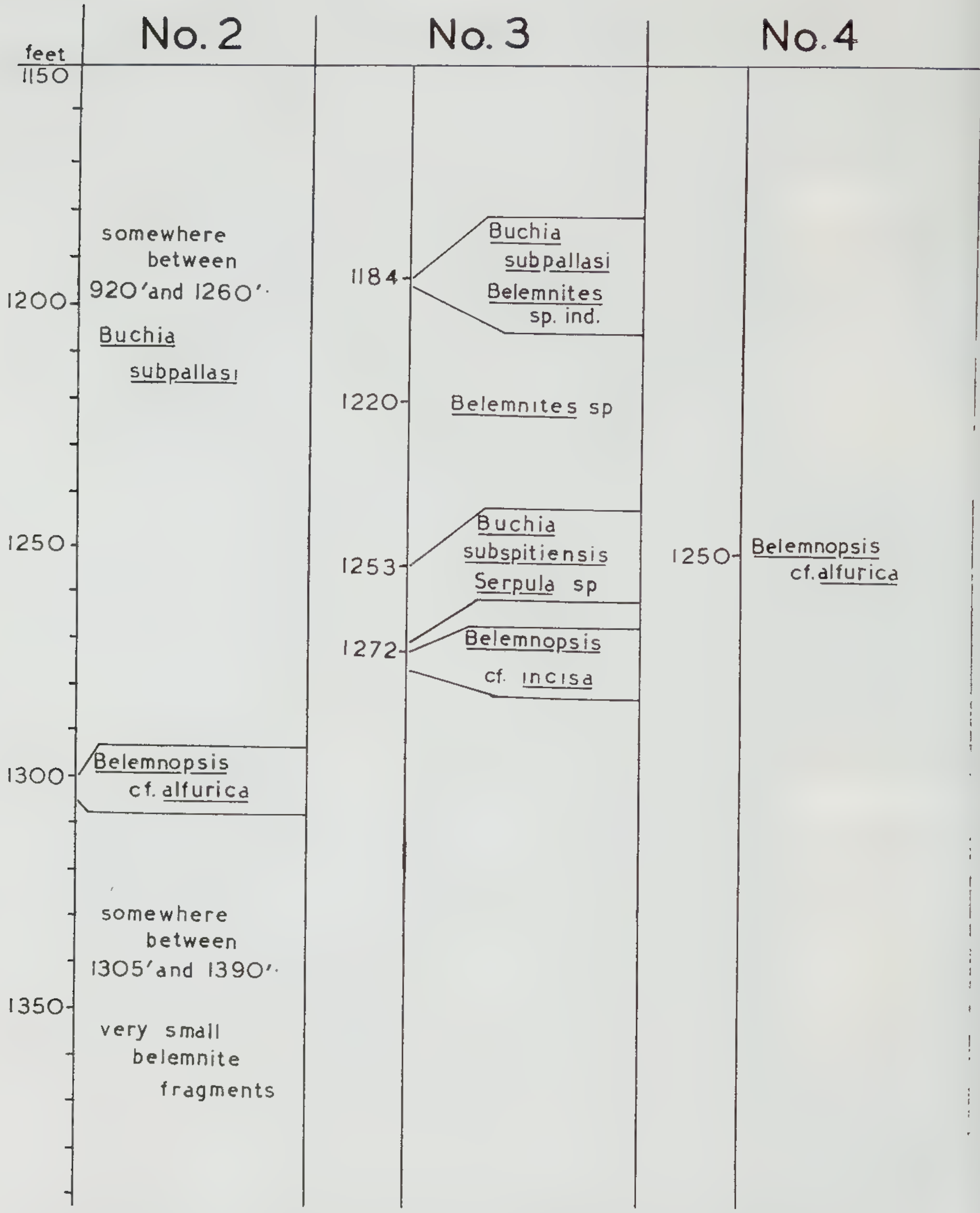
Depth from surface. Feet	
1120	Grey puggy shale with hard nodules and pyrites.
1158	Grey puggy shale with hard knobs.
1159	Hard limestone band.
1161	Grey puggy shale with hard knobs.
1184	Grey puggy shale with hard knobs.
1185	Hard limestone band.
1189	Grey shale.
1190	Hard limestone.
1200	Grey shale.
1200 6″	Hard limestone.
1211 6″	Grey puggy shale.
1212	Hard limestone.
1215 6″	Grey puggy shale.
1216	Hard limestone.
1220	Puggy shale.
1221	Hard limestone.
1223	Puggy shale.
1230	Puggy shale.
1242	Puggy shale with hard knobs.
1243	Hard sandstone.
1252	Grey shale.
1253	Hard sandstone.
1270	Dark grey sandy shale with shells.
1272	Hard sandy shale.
1274	Fossilized greenstone.
1275 6″	Very hard crystallised sandstone with hard knobs.
1296	Soft sandy shale with hard knobs.
1302	Sandy shale with hard knobs.
1357	Micaceous shale with hard knobs and pyrites.
1386	Puggy micaceous shale with pyrites.
1397	Soft sandy shale with hard knobs and pyrites.
1405	Soft sandy shale with hard bands and pyrites.
1417	Shale with hard bands and pyrites.
1424	Sandy shale with very hard bands and pyrites.
1427	Very hard bands and pyrites in sandy shale.
1432 6″	Sandy shale.
1433	Dark band.
1436 6″	Very hard country (coarse grained sandstone).
1440	Puggy shale.
1444	Puggy shale.
1461	Fine and coarse sand with good water.
1464	Puggy shale.

The depths of the other three bores are:—No. 1, 1,459 feet; No. 2, 1,775 feet; No. 4, 1,476 feet. It is noticeable that the proportion of sandy strata increases with greater depths and in the deepest bore, No. 2, a series of "white sand and boulders" was encountered between 1,555 and 1,773 feet.

The Jurassic fossils described in this report have been brought up from bores 2, 3, and 4 from between 1,184 and 1,390 feet (see Table II) and on account of the lithological uniformity of the strata from the top shale layer down to about 1,500 feet it may be assumed that the entire series from about

950 to 1,500 feet is of Jurassic age. The sands and sandstones above the top shale layer are uncemented or very loosely cemented, glauconite is absent from these strata, and they contain no macrofossils. This series is unlike

TABLE II.



Distribution of fossils in artesian bores No. 2, No. 3, and No. 4, Broome, North Western Australia.

any known series of strata of Cretaceous age in Western Australia and is, therefore, thought to be younger. Cretaceous thus seems to be absent from this section. As to the sandy series in bore No. 2 below 1,500 feet, no indication of its age can be given.

The fauna is characterized by an association of species of *Buchia* with belemnites of the group of *Belemnopsis gerardi* Oppel. This assemblage is highly characteristic of late Middle to early Upper Jurassic strata in the Himalayas, the East Indies, and in New Zealand. The most important species of the Broome assemblage are:—

Buchia subspitiensis (Krumbeck).
Buchia subpallasi (Krumbeck).
Belemnopsis cf. *B. alfurica* (Boehm).
Belemnopsis cf. *B. incisa* Stolley.

The vertical distribution of these species can be seen in Table II. Although *Buchia subpallasi* in bore No. 3 occurs at a higher level than *B. subspitiensis*, these two species cannot be considered as good horizon-markers. In certain facies on Misool both species have been found together in the same stratum, and I will, therefore, here speak of this fauna as of the *subspitiensis-subpallasi* assemblage.

Fig. 1.—Map of part of Australia and the East Indian Archipelago, showing ▲ occurrences of *Buchia malayomaorica*, ● occurrences of *Buchia subspitiensis* and *B. subpallasi*, and |||| distribution of marine Bajocian.

AGE AND PALAEOGEOGRAPHIC RELATIONSHIPS OF THE FAUNA.

Contemporaneous faunas have a wide distribution in the Himalayan-Australasian realm and our knowledge of them is due to a number of workers, including Uhlig, Holdhaus, Wanner, Krumbeck, Stolley, Zittel, Boehm, Trechmann, and Marwick. As may be expected, the relationships of the new Australian fauna are closest with that of the East Indies, particularly with that of the Timor-East Celebes geosyncline (Umbgrove, 1938), where rocks containing *Buchia* and belemnites of the group of *Belemnopsis gerardi* are found from Rotti and Timor in the south to Misool in the north (fig. 1). Contemporaneous deposits with either *Buchia* or belemnites of the *gerardi* group are also known from the eastern and northern borderland of the geosyncline, viz., from the Vogelkop on New Guinea (Broili, 1924), and from the Soela islands, Mangola and Taliaboe (Boehm, 1905, 1907). The most complete section is at present known from Misool and neighbouring islets where the field relations have been worked out by Boehm (1910) and by Wanner (1910), and more recently by Weber (communicated in papers by Wanner, 1931, and by Stolley, 1934a). Table III represents a somewhat condensed summary of the Oxfordian to Neocomian stratigraphy and the vertical distribution of species of *Buchia* and *Belemnopsis* in this region which has been compiled from recent papers published by Krumbeck and by Stolley in 1934. For data concerning the geology as well as geological maps of Misool and other East Indian islands mentioned below, the reader is referred to Rutten's comprehensive summary (1927).

TABLE III.

The Oxfordian-Neocomian sequence of Misool and the vertical distribution of *Buchia* and *Belemnopsis*.

—	—	*Buchia.*	*Belemnopsis.*
Neocomian	Upper Fatjet limestone of Fatjet [1] and Misool	....	*B.* cf. *tanganensis*
Neocomian - Upp. Jurassic	Lower Fatjet limestone of Misool	....	*B. misolica* *B.* cf. *gerardi*
Upper Oxfordian	Uppermost Fatjet shale of Fatjet	*B.* cf. *subspitiensis*	*B. gerardi*
	Inoceramus limestones and marls = Upper Fatjet shale	*B.* sp.	
	Inoceramus limestones and marls = Lower Fatjet shale	*B. malayomaorica* (in lower part)	*B. gerardi*
Middle Oxfordian	Lilintá marls		*B. moluccana*
Upp. Lower Oxfordian	Marly limestones of Lilintá [2]	*B.* cf. *subspitiensis* *B.* cf. *subpallasi*	*B. indica* *B. moluccana*
Lower and middle Lower Oxfordian	Demú limestone	....	*B. alfurica*, *B. incisa* *B. indica*, *B.* cf. *indica*
	" Aucellen-Sandstein " and tuff	*B. subspitiensis* *B. subpallasi*	*B.* cf. *alfurica* *B.* cf. *incisa*

[1] Fatjet is a small islet off the south coast of Misool. [2] Lilintá is a place on the south coast of Misool.

We shall first consider the significance of the *Buchia* species. For many years Zittel's early description in 1864 of a find of *Buchia* (*"Aucella plicata"*) from Kawhia Harbour, New Zealand, was the only recorded occurrence of this genus in the Indo-Pacific region which still puzzled Pompeckj in 1901.

We know now, thanks mainly to the work of Holdhaus, Krumbeck, Boehm, Trechmann, and Marwick, that dense populations of *Buchia* existed in the eastern Tethys during late Middle and early Upper Jurassic time.

Two important *Buchia* assemblages have been recognised in the sequence on Misool, viz. (1) the *subspitiensis-subpallasi* assemblage of the "Aucellen-Sandstein"* and (2) the *malayomaorica* assemblage in the lower part of the *Inoceramus* limestones and marls. This latter assemblage has the wider distribution in the East Indies where it is known from Timor, Rotti, Jamdena, Ceram, Boeroe, the Soela islands, Misool, Boeton, and the Vogelkop, New Guinea (see Wandel, 1936, p. 461), but, unlike the *subspitiensis* assemblage, it is absent from the Himalayan region. On the other hand, *Buchia malayomaorica* is also represented in New Zealand. In 1911, Boehm referred certain forms from Kawhia Harbour to "*Aucella plicata*" and Trechmann (1923) retained this name for the same group, but Marwick (1926), realising important differences from typical *Buchia plicata*, renamed these fossils *Aucella boehmi*. However, Krumbeck (1923) and again Wandel (1936) pointed out that this New Zealand species is apparently identical with *Buchia malayomaorica* which has priority. Further proof of the identity of the two species is given by the fact that Marwick included one of Broili's (1924) "*Pseudomonotis*" from the Vogelkop, New Guinea, in *Buchia boehmi* and that the same specimen was identified as *Buchia malayomaorica* by Wandel in 1936. Dr. J. Marwick kindly sent me a few specimens of *Buchia boehmi* from Kawhia Harbour and I was thus in a position to convince myself of the identity of this species with *Buchia malayomaorica*.

Buchia malayomaorica has not yet been found in Western Australia, but it is by no means unlikely that it will be discovered in the future.

In New Zealand (Marwick 1934), the strata with *Buchia malayomaorica* are overlain by strata with *Buchia plicata* Zittel (1864), redescribed by Marwick in 1926 and by Wandel in 1936. In 1934 Marwick (p. 949) stated that the succession *B. malayomaorica* (= *boehmi*) — *B. plicata* illustrated very well the developmental tendencies of the genus elsewhere, viz., "obliteration of the radial ornamentation, concentric rippling of the shelly layer, involution of the umbo in the left valve, flattening of the right valve" as expressed by Holdhaus in 1913. Some of these evolutionary trends had already been described by Pompeckj in 1901. In the Boreal province the more advanced stage in the development of *Buchia* is represented by such species as *B. bronni* and *B. pallasi* which are considered by Krumbeck to be very closely related to *B. subspitiensis* and *B. subpallasi*. *B. plicata* is the equivalent representative in New Zealand.† This was also realised by Krumbeck in 1934 when he wrote (p. 435): "Der *subspitiensis*-Horizont dürfte auf Neuseeland vertreten sein durch Trechmann's *Aucella spitiensis* Holdh. und *A. blanfordiana* (Stol.) Holdh." He had, however, overlooked the fact that

*According to Krumbeck (1934) Wanner's "Aucellen-Sandstein" series is made up of alternating layers of siliceous marls and calcareous sandstones. *Buchia subpallasi* seems to be confined to the siliceous marls, whereas *B. subspitiensis* is found in both rock types. For the sake of brevity I shall adhere to Wanner's original designation "Aucellen-Sandstein."

†The holotype of *Buchia plicata* Zittel (see Wandel, 1936, pl. 15, figs. 7a, b) is very similar to *B. subspitiensis* in the obliquely truncated anterior margin of the left valve, but differs in the much stronger curvature of the umbo. The specimen figured by Marwick (1926) on pl. 71, fig. 8, is similar to the holotype except for its greater width of the anterior portion. The specimen figured by the same author on pl. 71, fig. 9, has a rather acute umbo and resembles more closely *B. subpallasi* with which it might even be identical. Kruizinga's opinion (1926, p. 18) of the identity of *B. plicata* with *B. malayomaorica* is not supported by the facts.

Marwick had shown that the specimens thus identified (with reservation) by Trechmann were identical with the typical *Buchia plicata* (Zittel) and that they came from younger beds than *Buchia malayomaorica* (= *plicata* Boehm, not Zittel, = *boehmi* Marwick).

Whereas in New Zealand, as could be normally expected, the more advanced *plicata* assemblage follows upon the more "archaic" *malayomaorica* assemblage, in Misool we are confronted with the remarkable fact that the more advanced *subspitiensis-subpallasi* assemblage is found in strata considered to be well below the strata with *B. malayomaorica.* Realizing the fact that *B. subspitiensis* and *B. subpallasi* show more advanced features than any other species of *Buchia* of Oxfordian age, Krumbeck even suggested that the Aucellen-Sandstein of Misool might be of Kimmeridgian age, although general stratigraphical evidence (see Wanner, 1931) seemed against such a determination. On the strength of the belemnites Stolley (1934a) correlates the sequence from the Lilintá marls to and including the Fatjet shales with the Wai Galo fauna of Taliaboe which is of Divesian (Mesoxfordian) age (see Spath, 1933, p. 872), but since he draws the Dogger-Malm boundary below the Aucellen-Sandstein it must be assumed that the latter, too, in his opinion, belongs to the Upper Jurassic.

The species of *Buchia* from the Spiti shales of the Himalaya (Holdhaus, 1913), especially *B. blanfordiana* and *B. spitiensis,* are closely related to the *subspitiensis* assemblage of Misool and to the *plicata* assemblage of Kawhia Harbour, but unfortunately their exact relative position in the sequence is unknown. They are, however, younger than the Belemnite beds at the base of the Spiti shales which contain species of the group of ***Belemnopsis gerardi*** (Uhlig, 1910) and which are considered to be of about Argovian (Neoxfordian) age. The overlying Chidamu beds in which *Buchia* apparently occurs, have an ammonite fauna which, according to Spath (1933, p. 805), is not older than Upper Kimmeridgian. The discrepancy of the determination of the age of the *subspitiensis* assemblage at Misool on the one hand and the *spitiensis-plicata* of Spiti and Kawhia on the other, is accentuated by Krumbeck's suggestion (1934, p. 445) that *Buchia subspitiensis* itself may be represented in the Spiti shales by Holdhaus' specimen figure 10 a-c on pl. 97.

It should be noted that the group of *B. subspitiensis* also seems to be represented on New Caledonia (*Aucella* cf. *leguminosa,* Piroutet, 1903), where its exact age, however, apparently is unknown.

Regarding the significance of the belemnites found mostly at or below the horizon with *Buchia subspitiensis*:—As has been said above belemnites of the group of *Belemnopsis gerardi* are characteristic members of the *Buchia* series throughout the Himalayan-Australasian realm. As early as 1911 Uhlig (p. 390) pointed out not only the importance of *Belemnopsis gerardi* in the Spiti sequence, but also the eastward extension of the *gerardi* fauna into the East Indian region, where the importance of canaliculate belemnites had become apparent after the publication of Boehm's first palaeontological results in 1905 and 1907. Later studies by Kruizinga (1921) and by Stolley (1929, 1934 b) have contributed materially to our knowledge of the East-Indian *Belemnopsis* fauna, their stratigraphical distribution and their relationships to the New Zealand forms described by Zittel in 1864, Hector in 1878, and Trechmann in 1923. Discussions by Spath (1927, 1933) have added valuable information to the relationships between the East-Indian species and those of the Spiti shales and of Kacch.

Stolley distinguishes two groups of canaliculate belemnites, viz., the group of *Belemnopsis canaliculata* and the group of *B. gerardi.* The former, characterised by a very narrow and sharp cut ventral groove, is but sparsely represented in the Himalayan-Australasian province, where the second group is found in abundance. The stratigraphical value of these belemnites has been much discussed. Stolley, in 1929, stressed their usefulness for correlation, if sufficient care in the determination of the species were taken, but their value for this purpose was doubted by Boehm as early as 1909 and again by Spath in 1927 and 1933. Whatever their importance may be in strata, where they occur in great number and variety, determinations on the basis of a few specimens, as in the case of the Australian finds, must be made with great care and should be accepted with due reservation. The Australian specimens belong to at least two species and are here compared with *Belemnopsis alfurica* (Boehm) and with *B. incisa* (Stolley). *B.* cf. *alfurica* is found in glauconitic sandstone immediately underlying the strata with *Buchia subspitiensis* in bore No. 3, whereas *Belemnopsis* cf. *incisa* occurs at a slightly higher level in bore No. 4 and at a somewhat lower horizon in bore No. 2.

In Misool, the typical species are characteristic of the Demú limestone, immediately above the Aucellen-Sandstein with *Buchia subspitiensis* and *B. subpallasi,* but it may be significant, that Stolley (1934 b) reports *Belemnopsis* cf. *alfurica* and *B.* cf. *incisa* from the Aucellen-Sandstein itself. If these specimens were conspecific with the Australian specimens mentioned here, the *Buchia-Belemnopsis* assemblage of Broome would be identical with that of the Aucellen-Sandstein of Misool. In Misool, *Belemnopsis gerardi* is younger than *B. alfurica,* but both species seem to be associated in the basal Belemnite bed of the Spiti shales, the age of which can be taken to be about Argovian or perhaps very slightly older (Spath 1933, pp. 661-662), but at any rate younger than the age assigned to the Aucellen-Sandstein by Wanner and by Stolley.

Taking all these facts into consideration it can be said that the fossiliferous strata in the Artesian bores at Broome most probably are an equivalent of the "Aucellen-Sandstein" of Misool. Attention must, however, be called to the fact that specimens of *Buchia,* doubtfully referred to *B. subspitiensis* and *B. subpallasi* have also been recorded from higher horizons in the Misool series, notably from the marly limestones of Lilintá and from the uppermost Fatjet shales. This in conjunction with the fact that the belemnites can be compared most closely with forms which are most common in horizons slightly above the Aucellen-Sandstein, may point to a slightly younger age of the strata concerned. The age of the strata should be approximately Oxfordian, most likely not early Oxfordian, but Divesian or Argovian. However, in view of the advanced stage of the *subspitiensis-subpallasi* fauna whose equivalents in the Himalayas are definitely post-Argovian and in New Zealand younger than the Oxfordian *malayomaorica* fauna, the possibility of a Kimmeridgian age of the fauna should not be altogether excluded.

CONCLUSION.

The differences between the development of the Jurassic in the western and in the eastern part of the East Indian Archipelago were fully set out by Wanner in 1925 and summarised and generalised by Umbgrove in 1938. Umbgrove recognised the existence of a geosynclinal basin which was in

existence throughout the Mesozoic in the eastern part of the archipelago which he termed the "Timor-East Celebes geosyncline" and it is with the Jurassic deposits of this geosyncline that the Jurassic strata of Broome have their closest relationships. In fact, it seems to be evident that the Australian occurrence forms the continuation of the Jurassic belt of the Timor-East Celebes geosyncline.

In a paper read at the Canberra meeting of the Australian and New Zealand Association for the Advancement of Science in January, 1939, I produced some evidence for the existence of a geosynclinal basin ("Westralian geosyncline") along the western margin of the Australia shield which came into existence not later than in Permian time and which I considered to be continuous with the Timor-East Celebes geosyncline of Umbgrove. The discovery of Jurassic beds with the typical facies of the Timor-East Celebes geosyncline in the northern part of this Western Australian trough gives further evidence of the similarities in the geological history of these two areas.

DESCRIPTION OF THE FAUNA.

Genus **SERPULA** Linné.

Serpula sp.

Plate I. Fig. 13.

The genus Serpula is represented by two specimens which are most similar to *Serpula convoluta* Goldfuss from the Middle Jurassic of Germany. The specimens occur in strata yielding *Buchia subspitiensis*. The better preserved specimen consists of slightly more than two volutions of the tube, of which the last one tends to become free from the preceding one. Where it is broken off the tube has attained a diameter of 5.7 mm. The wall of the tube consists of numerous fine concentric calcareous layers, and has a structure rather different from that described for Serpulidae by Gertrud Götz in 1931; in particular, no traces of the outer layer which is composed of parabolic transverse lamellae, can be discovered, but the great number of the concentric lamellae excludes the specimens from the gastropod family Vermetidae. The find is here recorded, because of the absence of comparable forms in contemporaneous East Indian deposits.

Occurrence: Broome, Artesian bore No. 3, 1,253-1,270 feet below sea-level.

Genus **BUCHIA** Rouillier.

Synonym: *Aucella* Keyserlingk, 1846.

The genus *Buchia* was established by Rouillier in Bulletin de la Société Impériale des Naturalistes de Moscou, vol. 18, p. 289, 1845, with *Avicula mosquensis* von Buch as the only species mentioned. This species, therefore, is the genotype by monotypy.

Buchia subspitiensis (Krumbeck).

Plate I, Figs. 1-7.

1934 *Aucella subspitiensis*, L. Krumbeck, Neu. Jahrb. etc., Beil.-Bd. 71 B, pp. 439-448, pl. 14, figs. 1-12, pl. 15, figs. 1-8.

1936 *Aucella* cf. *subspitiensis*, G. Wandel, Neu. Jahrb. etc., Beil.-Bd., 75 B, pp. 462-463.

Four left valves are available, two of them with the umbo destroyed, but all with fragments of the shell preserved and very little distorted.

A redescription of this species seems unnecessary in view of Krumbeck's exhaustive description to which the reader can be referred and which can be applied in almost every detail to the specimens here under consideration. One of the main features of the species is the obliquely truncated anterior end of the left valve. Also, the rather elongated shape and the short, stout, and not very strongly incurved umbo of the left valve are important.

The ornamentation consists mainly of concentric ridges differing in prominence in different specimens. The four specimens show all transitions from narrow, regularly spaced ridges which are only slightly raised above the general surface of the shell, to broader and stronger, somewhat irregularly spaced and more prominent folds. The same range of variation is also evident among the specimens from Misool when, e.g., the specimens figured by Krumbeck on pl. 14, figs. 1, 2 and 5, are compared.

Krumbeck described the radial ornamentation as very weak and the same can be said of the Australian specimens. Radial striae are well developed in the umbonal region of the left valve, where they are plainly visible for a distance of at least 5 mm. from the umbo. Farther on they become weaker and seem to fade out before the middle portion of the shell is reached. In one specimen, however, traces of the radial ornamentation are still recognizable behind the middle of the shell. These radial striae are not quite straight, but undulate in a somewhat irregular manner between the concentric ridges. The finely "granulated" surface, due to intersection of radial and fine concentric striae, which is illustrated by Krumbeck on pl. 15, figs. 7 and 8, is not visible in any of the Australian species.

The close relationships of this species with *Buchia bronni* Rouillier (see especially Lahusen, 1888, pl. 1, fig. 1) and with *B. spitiensis* Holdhaus have been fully discussed by Krumbeck and the importance of these similarities for the determination of the age of the strata has been discussed above. It may be added that among the boreal forms *B. lindstroemi* Sokolov from the Kimmeridgian and Volgian of Orenburg, Petchoraland, and Spitsbergen seems to be another closely related species (see Sokolov and Bodylevsky, 1931, p. 35). There is hardly any pre-Kimmeridgian species with which *B. subspitiensis* might be compared.

Occurrence: Broome, Artesian bore No. 3, 1,253-1,270 feet below sea-level.

Buchia subpallasi (Krumbeck).

Plate I, Figs. 8-12.

1934 *Aucella subpallasi,* L. Krumbeck, Neu. Jahrb., Beil. Bd. 71 B, pp. 450-454, pl. 15, fig. 11, pl. 16, figs. 1-10.

In addition to shell fragments one left valve and one right valve, both partly damaged, are available.

As in the case of the preceding species Krumbeck's description of *Buchia subpallasi* is exhaustive and nothing can be added to the knowledge of the species by the study of the limited Australian material. The species is characterised mainly by the long and acute umbo of the left valve which is strongly incurved with a slight forward twist. It is distinguished from the boreal *B. pallasi* as figured by Lahusen (1888, pl. 1) mainly by the greater prominence of the umbo and by the absence of the posterior ear of the left

valve which is slightly developed in the latter species. The Australian specimen agrees particularly well with the Misool specimens illustrated by Krumbeck on pl. 16, figs. 5 and 7.

The right valve, too, is in close agreement with the valves described from Misool. It is rather strongly convex in the dorso-ventral section and much less so in the longitudinal section. The byssus ear is small and has one radial fold as described by Krumbeck. The ornamentation of the left valve consists of weak concentric folds which are in some cases dichotomous, as also mentioned by Krumbeck. No traces of radial ornamentation are seen on the left valve; this is also absent in all the Misool specimens examined by Krumbeck, except one. The right valve has very fine concentric folds, much weaker than those of the left valve and apparently more irregularly spaced. There are also traces of very fine radial lines on the right valve. This valve resembles most closely that figured by Krumbeck on pl. 16, fig. 6. Its ornamentation is so faint that it can only be seen upon closer examination of the specimen. Krumbeck does not mention the presence of any radial ornaments in any of his Misool specimens.

Occurrence: Broome, Artesian bore No. 3, at 1,184 to 1,185 feet below sea-level. Perhaps also in bore No. 2, somewhere between 920 and 1,260 feet.

Genus **Belemnopsis** Bayle.

In spite of diligent efforts by Boehm (1905, 1907), Uhlig (1910), Spath (1927, 1933), Stolley (1929, 1934), and others to clarify the taxonomy of the Himalayan-East Indian species of *Belemnopsis* the systematic relationships of the many species established by Oppel, Waagen, Boehm, and Stolley are still far from being satisfactorily understood. All authors agree that at least some of the species of the *gerardi* group are indistinguishable unless a number of well preserved specimens is available. The following determinations of fragments obtained from the Artesian bores at Broome must, therefore, be accepted with every reservation.

Belemnopsis cf. **B. alfurica** (Boehm).

Plate I, Figs. 14-21.

cf. *Belemnites alfuricus*, J. Boehm, Palaeontogr., Suppl. Bd. IV., 1905, p. 56, pl. 8, figs. 4, 5.

cf. *Belemnopsis alfoericus*, P. Kruizinga, Jaarb. Mijnw. (1920), 1921, p. 8, pl. 2, figs. 1-3.

cf. *Belemnopsis alfurica*, E. Stolley, Pal. v. Timor, XXIX., 1929, p. 172.

Three fragments are here referred with reservation to this species with which it seems to agree more closely than with the closely related *Belemnopsis gerardi* Oppel (established in 1863, p. 273, described and figured in 1865). Unfortunately, Oppel when describing this species in detail in 1865, referred to it specimens now considered to belong to three different species. Stolley's concept of the species (1929, p. 151) was based on Oppel's specimen, fig. 3 (see Oppel, 1865, pl. 88), but Spath (1933, p. 662) has correctly rejected this choice of holotype, because this specimen was referred to the species by Oppel with reservation (explanation of pl. 88, fig. 3: "Bruchstück eines grösseren, vermuthlich zu Belemnites Gerardi gehörigen Exemplares."). Both Stolley and Spath regard Oppel's specimen fig. 2 as belonging to *Belemnopsis alfurica* (Boehm) and Oppel's specimen fig. 1 must, therefore, be selected as the holotype of *Belemnopsis gerardi*. Stolley

was of the opinion that this specimen should be referred to *B. aucklandica* Hauer, which is probably not correct, as already pointed out by Spath. If the holotypes of these two species should be found to be conspecific, the name *gerardi* would have priority over *aucklandica*, which was established in 1864 (Zittel, 1864, p. 29). From a comparison of the Australian specimens with Oppel's figures as well as with the improved cross-section of the holotype of *B. gerardi* reproduced by Boehm (1905, p. 55, text-fig. 20) and with Boehm's figures of *B. alfurica* (Boehm, 1905, pl. 8 and figures on p. 54) it appears that the Australian specimens differ from the holotype of *B. gerardi* in their more circular cross-section and in the deeper ventral groove and are, in this respect, more similar to Boehm's original specimens of *B. alfurica* as well as to Oppel's specimen fig. 2, which is regarded as a representative of the same species.

One specimen from bore No. 2, 1,300-1,305 feet (pl. I, figs. 17, 18) is a short cylindrical fragment of a guard with a lateral diameter of 14.3 mm. and a dorso-ventral diameter of 14.4 mm. The ventral groove is 2 mm. deep. No lateral lines are visible, but the sides are slightly worn. This specimen agrees well with specimens of *B. alfurica* figured by Boehm in 1905, but it is also similar to specimens which have been referred to *B. gerardi* by Uhlig (1910, pl. 93, figs. 9 a, b), by Kruizinga (1921, pl. 1, fig. 1) and by Stolley (1929, pl. 249, fig. 3).

A fragment of the lower part of a guard from bore No. 4, 1,250 feet (pl. I, figs. 14-16), has a dorso-ventral diameter of 14 mm. at its upper end and a lateral diameter of about 14 mm. (now smaller owing to slight wear of one side). The ventral groove is much shallower than in the preceding specimen; it is less than 1 mm. deep at the upper end and fades out at a distance of about 14 mm. from the tip of the guard. The lateral lines are clearly visible on one side of the guard, but disappear at about the same distance from the tip as the ventral groove. At this place (about 14 mm. from the tip) the dorso-ventral diameter of the guard is 9.2 mm., the lateral diameter 9.0 mm.

This specimen resembles *B. alfurica* Boehm in its slender shape; the guard of *B. gerardi* tapers more abruptly at its lower end. In this respect the specimen also bears close resemblance to the New Zealand species *B. aucklandica* Hauer (see Zittel, 1864, pl. 8, fig. 2) which is also reported from Jamdena and Timor in the East Indies (Stolley, 1929, p. 170). The lateral lines mentioned above are also known in *B. alfurica* Boehm, but they are likewise characteristic of *B. gerardi* as first noticed by Rothpletz in 1892 (p. 104) and confirmed by Boehm in 1905 (p. 56). They are, however, absent in *B. aucklandica* as expressively mentioned by Hauer (Zittel, 1864, p. 29).

In conclusion it can be said that the first two specimens mentioned above can be compared with either *B. gerardi* Oppel or with *B. alfurica* Boehm, whereas the third specimen resembles most closely *B. alfurica* and *B. aucklandica* Hauer. If these specimens represent one and the same species the relationships may be closest with *B. alfurica*.

This species has a wide distribution in the East Indies, where it is reported from Taliaboe, Mangoli, Misool, and Boeroe, and with reservation from Timor, Ceran, and East Celebes (Stolley, 1934 c). It also occurs in the Spiti shales of the Himalaya. In Misool, according to Stolley, it is

characteristic of the lower part of the Oxfordian sequence (see Table III). Its significance has been discussed in a preceding section.

Occurrence: Broome, artesian bore No. 2, 1,300-1,305 feet, bore No. 4 1,250 feet below sea-level.

Belemnopsis cf. **B. incisa** Stolley.

Plate I. Figs. 22, 23.

cf. *Belemnopsis incisa*, E. Stolley, Neu. Jahrb., Beil. Bd. 73 B., 1934, p. 51, pl. 2, fig. 2.

Neither the description nor the figures given by Stolley when he established this species are quite sufficient to determine exactly its relationships. He states that the guard most resembles medium-sized specimens of *B. gerardi*, but that it is clearly distinguished by the particularly sharp and deep cut ventral groove. He also states that, if the lateral sides are prolonged beyond the incision made by the ventral groove, a slightly oval cross-section is obtained, whereas a similar procedure in *B. gerardi* results in an almost circular cross-section.

Specimens obtained from bore No. 3, just below the strata with *Buchia subspitiensis*, seem to agree with this description. The best of the specimens (pl. I, figs. 22, 23) is the upper portion of a guard, with part of the alveolus, however, broken off, whose lateral diameter increases from 10.8 mm. to about 11.6 mm. at the lower end. The dorso-ventral diameter at the upper end is 10.6 mm. The ventral groove is very narrow and about 2 mm. deep, with steep sides. The cross-section agrees well with that described for *B. incisa* by Stolley. None of the specimens is well enough preserved to show whether or not lateral lines are developed.

Until better descriptions or actual specimens of *B. incisa* come to hand the specimens mentioned above must be referred to this species with reservation.

Occurrence: Broome, Artesian bore No. 3, 1,272 feet to 1,273 feet 9 inches, in glauconitic sandstone.

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EXPLANATION OF PLATE I.

All figures natural size, unless otherwise stated.

Figs. 1-7.—**Buchia subspitiensis** (Krumbeck). Broome, bore No. 3, 1,253-1,270 feet.

1, 2, left valve with slightly damaged umbo. No. 2/1912a.
7 enlarged portion of same specimen.
3, 4, 5, another left valve with rather regular concentric ornamentation (fig. 3 enlarged 1.5 X). No. 2/1912b.
6, large left valve with stronger irregular concentric ornamentation, No. 2/1913.

Figs. 8-12.—**Buchia subpallasi** (Krumbeck). Broome, bore No. 3, 1,184-1,185 feet.

8, 9, 11, left valve, No. 2/1910; 10, right valve, No. 2/1908; 12, byssus ear of right valve, enlarged 3 X, drawn from the external mould, No. 2/1909, left by specimen fig. 10 with portions of the ear still adhering to the mould.

Fig. 13.—**Serpula** sp. Broome, bore No. 3, 1,253-1,270 feet. No. 2/1911.

Figs. 14-21.—**Belemnopsis** cf. **B. alfurica (Boehm)**. Broome. (Figs. 14 and 20 show lateral lines.)

14, 15, 16, specimen from bore No. 4, 1,250 feet.
17, 18, specimen from bore No. 2, 1,300-1,305 feet. No. 2/1906.
19, 20, 21, another specimen from the same level.

Figs. 22, 23.—**Belemnopsis** cf. **B. incisa** Stolley. Broome, bore No. 3, 1,272-1,272 feet 9 inches. No. 2/1914.

All specimens are in the Geological Survey of Western Australia, except specimen figs. 14-16 which is in the collection of Mr. Bernard E. Bardwell, Broome, Western Australia.

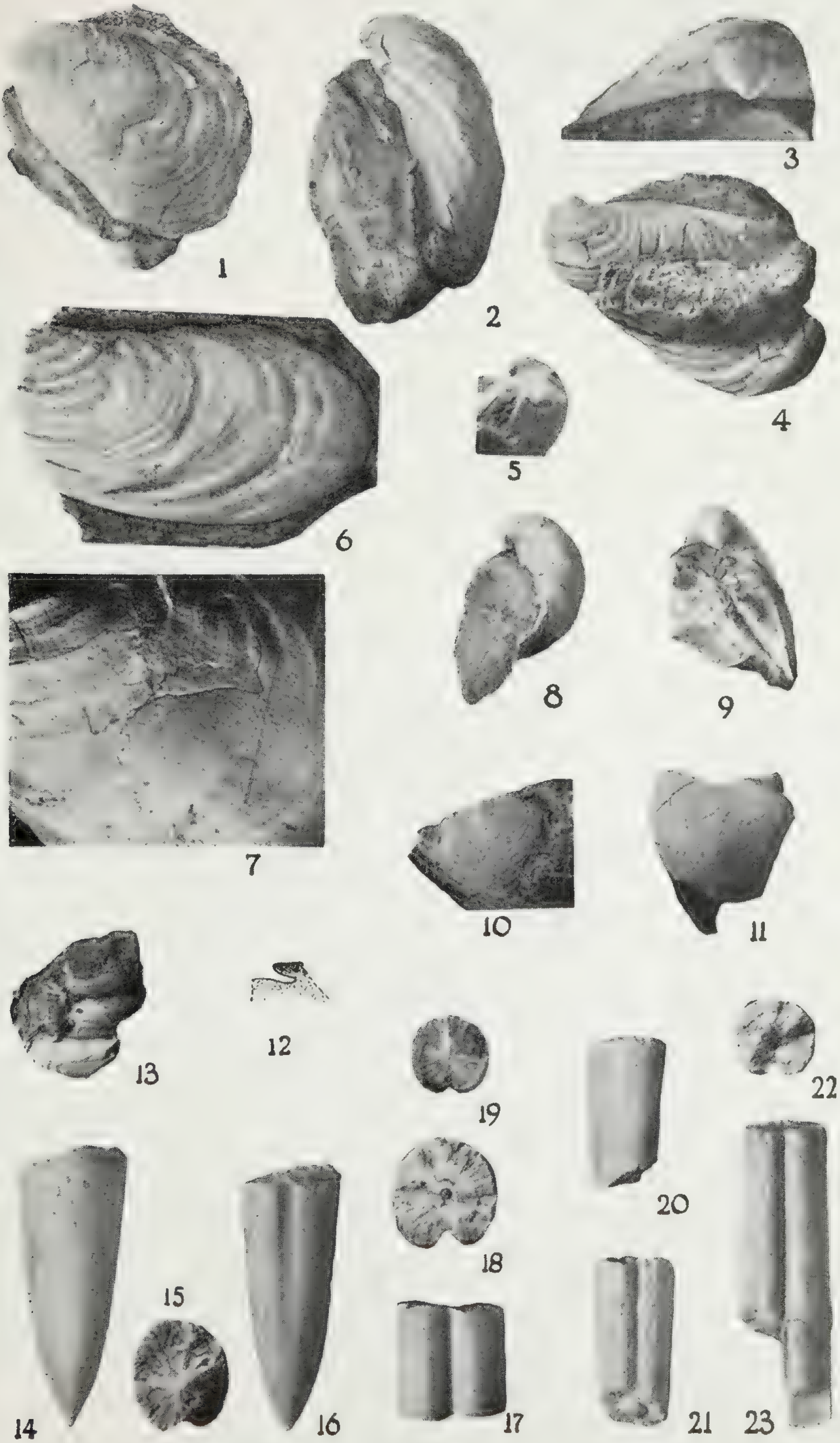

PLATE I.

11.—ANALYSIS OF SOIL COLLOIDS BY X-RAY DIFFRACTION METHODS.

By J. SHEARER, M.Sc.* and W. F. COLE, B.Sc.

Read: 9th April, 1940. Published: 7th October, 1940.

CONTENTS.

I. INTRODUCTION.

In 1916 Debye and Scherrer in Germany and Hull in America developed a method (termed the powder method) of investigating the crystal structure of crystalline material in the form of powder. If a monochromatic beam of X-rays defined by pin-holes is directed on to a small rod of the powder in a suitable container, diffraction lines in the nature of a "spectrum" appear on a cylindrical photographic film concentric with the powder. These diffracted lines are the intersections with the film of cones of rays diffracted from the powder, each cone being characterised by a semi-vertical angle of $2\theta_{hkl}$† where θ_{hkl} is defined by Bragg's equation $n\lambda = 2d_{hkl} \sin \theta_{hkl}$. A particular crystalline material is characterised by a particular distribution of lines and of line intensities in its "spectrum" or X-ray diffraction pattern. The components of a mixture of crystalline materials may be recognised if the pattern of each component in the composite pattern can be identified. Colloidal particles greater than about $0 \cdot 1 \mu$ may be sufficiently crystalline to react in this way and so a mixture may be analysed into its components. A decade or more ago attempts were first made by workers in Europe and America to apply this powder method to the investigation of the colloidal clay content of soils.

In this paper the authors give an account of a technique developed in general for the investigation of crystalline material in powdered form and in particular for the investigation of soil colloids. An account is also given of results obtained for two local soil samples.

The clay samples investigated were supplied by the State Department of Agriculture through Dr. Teakle, whose enthusiasm first aroused the interest of the senior author in this work. Mr. G. H. Burvill, Agricultural Adviser to the State Department of Agriculture, was responsible for the actual separation of the clays.

* Lecturer in Physics in the University of Western Australia.

† See, for example, W. H. and W. L. Bragg, "The Crystalline State," Chapters III. and IV.

II. MATERIALS.

The following particulars with regard to the location of the profile from which the soil samples were obtained, the method of separation of the clay fractions and analytical data with respect to soil samples and clay samples were kindly supplied by Mr. Burvill.

A. *Location.*

The two samples supplied (A1346 and A1351) represent the subsoil (6 inches–30 inches) and deep subsoil (120 inches–144 inches) respectively, in a profile of the soil type *Circle Valley* sand taken at Red Lake (longitude 121° 45′ E.; latitude 33° 08′ S.) in the Salmon Gums district. They are typical of the subsoil and deep subsoil conditions over large areas in that district.

B. *Method of Separation.*

The clay separations followed in general the methods adopted in the procedure for mechanical analysis by the pipette method as described in C.S.I.R. (Aust.) Pamphlets Nos. 8 and 13, with the following variations:

(i) To avoid chemical changes the hydrogen peroxide treatment and the acid treatment were dispensed with. The omission of the former is presumed to be of little consequence as the organic content is very low.

(ii) From each soil sample two clay samples were prepared in one of which dispersion was made in distilled water; in the other caustic soda was used. Thus four clay samples in all were supplied.

(iii) Care was taken to avoid any heat treatment at any stage in the process. The clay was separated from the suspension by flocculation with calcium chloride, filtration, washing twice with 95% alcohol and air-drying.

The clay samples so prepared should contain most of the particles less than 2μ in effective diameter. The colour of A1346 is greyish yellow; that of A1351 pinkish brown.

C. *Analytical Data relating to Soil Samples.**

1. *Mechanical and Chemical Data.*

	A 1346	A 1351
Depth of sample (in inches)	6–30	120–144
	per cent.	per cent.
Coarse sand (2·0–0·2 mm.)	10·7	11·3
Fine sand (0·2–0·02 mm.)	26·1	28·1
Silt (0·02–0·002 mm.)	3·0	1·1
Clay (less than 0·002 mm.)	51·5	52·8
Loss on acid treatment	5·3	2·0
Moisture	6·1	7·0
Loss on ignition	7·0	5·4
Calcium Carbonate	3·6	*nil*
Total water soluble salts	0·679	1·216
Sodium Chloride	0·546	0·923
Soluble in Hydrochloric Acid—		
Lime (CaO)	1·603	0·011
Magnesia (MgO)	1·481	0·608
Potash (K_2O)	1·625	1·328
Soda (Na_2O)	0·646	0·719
Reaction (pH)	8·58	4·38

*Received from the Department of Agriculture and shortly to be published by G. H. Burvill, B. L. Southern and L. J. H. Teakle.

2. *Exchangeable Cations, excluding Hydrogen.*

Soil.	Total m.e. per 100 gms. of Soil.	Per cent. of total bases.			
		Ca.	Mg.	K.	Na.
A 1346	27·17	12	40	13	35
A 1351	18·23	0	47	10	43

3. *Chemical Analysis of Clay Fractions.*

—	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3
	%	%	%	
A 1346	47·92	22·99	10·33	2·75
A 1351	47·84	21·12	12·32	2·80

III. EXPERIMENTAL DETAILS.

X-Ray Unit and Radiation.—A Hilger-Mueller Improved X-ray goniometer spectrograph was used, with certain modifications alluded to below. Radiation was supplied by a Hilger all-steel gas X-ray tube energised by a 16 inch Victor induction coil with mercury make and break. In the case of the four clay samples exposures were obtained with filtered Cu radiation. In the case of the two samples of A1346 and the caustic soda dispersed sample of A1351, Fe radiation was also used. β lines appearing in a diffraction pattern obtained with unfiltered radiation may readily be identified by comparison with a pattern that has been obtained with filtered radiation.

Ni Filter and Method of Preparation.—The Cu radiation was rendered monochromatic by means of a $10\,\mu$ Ni filter. This filter served as a window for the X-ray tube throughout the course of the work. Its thickness was not sufficient to suppress the Cu $K\beta$ radiation in the case of heavily exposed lines, but as this occasioned no difficulty, the $10\,\mu$ filter was retained with a view to avoiding unnecessary loss of intensity.

It was found that a satisfactory way of preparing Ni foil of any desirable thickness was to deposit the foil electrolytically on a cathode consisting of a stainless steel button set in copper. Since the Ni film will not adhere to stainless steel, the portion overlying the button can readily be removed.

Collimation.—The X-ray beam was collimated by a long cylindrical channel, the diameter of which at each end was limited by two short cylindrical stops fitting into the channel. Each stop was of total length (including a collar) of 1·5 cm., and the total length of the collimating system was 6·2 cm. The diameter of the stops used in the course of this work was 0·5 mm. The powder preparation was mounted at a distance of 0·4 cm. from the near end of the collimating system and 8·6 cm. from the window of the tube. This method of collimation, which involved a modification in the design of the original unit, was adopted after trial of other methods. At 2·8 cm. from the preparation the direct beam so collimated was about 0·7 mm. wide and about 1·2 mm. high.

Mounting of Powder.—The clay fractions were held in small celluloid containers of internal diameter not exceeding 0·35 mm. and of wall thickness approximately 0·1 mm. To make these containers, short straight lengths of

copper wire of diameter 0·32 mm. were coated with a smear of specially selected candle-grease and dipped into a solution of celluloid dissolved in acetone. When the acetone had evaporated, leaving a thin precipitate of celluloid on the wire, it was held in steam and the wire gently withdrawn. The powder was introduced with the help of a fine brush and a fine glass rod.

The preparation was adjusted so as to remain in the X-ray beam upon rotation. A method of mounting was developed which made it possible to change from one preparation to another with very little re-adjustment. In the course of the exposure, in order to ensure an accurately fixed mean position of the powder relative to the cylindrical photographic film, the preparation was continuously rotated by clockwork.

Mounting of Films.—Ilford double-coated X-ray film was used, in all cases backed by Levy-West Fluorazure intensifying screen. The screen was cut to size, shellaced along the cut edges and, to prevent the formation of creases, bent into the shape of the camera after the shellac was thoroughly dry. The film and intensifying screen were carried in specially designed black paper envelopes.

The cylindrical camera used had a radius of approximately 2·8 cm. Other cameras available have a radius of 4·3 cm. and 5·6 cm. respectively. The envelope and its contents were held in position by means of two metal bands (which held the envelope pressed against the camera), one at the top and one at the bottom. Additional clamping was provided for the one at the top by means of three small brass clamps.

Exposure Times, and Choice of Radiation.—Under normal operating conditions of 4 mA and about 60 K.V.P. suitable exposures were obtained in at most two hours with Cu Kα radiation. The photographs of the clay fractions so obtained, when compared with photographs of a pure substance (*e.g.*, KCl), showed a pronounced general scattering. As the scattering of the Cu radiation by the Fe present in the sample could explain this effect, photographs were taken with Fe radiation, but no marked improvement was observed. This change of radiation involved much longer exposure times. It appeared that factors such as the presence of amorphous material and the size of the particles were responsible for the scattered background. The insertion of Cu foil or Al foil in front of the film failed to improve the contrast.

Absorption of Direct Beam.—The direct beam was absorbed in a small rectangular chamber mounted in front of the film. The dimensions of the chamber (which was designed to replace the larger one supplied with the instrument) were made such that when it was placed close up to the film mounted in the smallest camera (radius 2·8 cm.), an X-ray shadow of approximately 3·5 mm. wide was obtained. A diffraction ring of this diameter corresponds to a spacing (d/n) of 25 A (with Cu Kα). The prominent montmorillonite spacing at 15 A could readily be recorded. This method of dealing with the direct beam was selected, as a result of experiment, in preference to the method of allowing the beam to pass out through a hole in the film.

Heat Treatment.—In view of the observations of other workers that the basal spacing of montmorillonite varies with the water content, and that the kaolinite pattern is destroyed at 500° C, provision was made for heating the colloid material in air in an electric furnace.

IV. DETERMINATION OF d/n BY A GRAPHICAL METHOD, AND ACCURACY OF RESULTS.

X-radiation of wave-length λ is reflected from a given set (hkl) of crysta lattice planes with interplaning spacing d_{hkl} at a glancing angle θ_{hkl} defined by Bragg's equation. Under the conditions of the powder method, these rays constitute a cone and all the possible (hkl) sets of lattice planes will give rise to the family of cones referred to in the introduction. The trace on the cylindrical film of any one of these cones is two symmetrical curved lines approximately arcs of a circle whose centre is the point where the direct beam leaves the camera. (In the case of a cone with semi-vertical angle greater than 90° the centre of the arcs is the point where the direct beam enters the camera). The Bragg angle θ may be deduced from a measurement of the maximum separation ($2s$) of these two arcs (the measurement being made along the film in the equatorial plane) and from the relation $\theta = s/2r$, where r is the radius of curvature of the film. (In the case of a cone with semi-vertical angle greater than 90°, $2s$ is the minimum separation).

A graphical method was devised for determining d_{hkl}/n from measurements of the corresponding $2s$. Dropping subscripts we have from Bragg's relation—

$$(d/n) \sin \theta = \lambda/2.$$

Expanding $\sin \theta$:

$$(d/n)\ (\theta - \theta^3/3! + \theta^5/5! - \ldots) = \lambda/2.$$

Substituting $\theta = s/2r$:

$$(d/n)\ [s/2r - (s/2r)^3/3! + (s/2r)^5/5! - \ldots] = \lambda/2.$$

Therefore:

$$(d/n)\ (s/2r)\ [1 - s^2/24r^2 + s^4/1920r^4 - \ldots] = \lambda/2;$$

and, finally,

$$(d/n)\ 2s\ [1 - (2s)^2/96r^2 + (2s)^4/30720r^4 - (2s)^6/20643840r^6 + \ldots] = 2\lambda r.$$

Taking logs we get, if r is constant:

$$\log (d/n) + \log 2s\ [1 - (2s)^2/96r^2 + \ldots] = \text{constant}$$

where the constant is $\log 2\lambda r$.

Write this:

$$\log (d/n) + \log f(2s) = \text{constant}.$$

A graph of $\log (d/n)$ plotted against $\log f(2s)$ will therefore be a straight line with gradient -1. If r varies $f(2s)$ is a function of r and the value of r in each term of $f(2s)$ that contains r will be the value appropriate to that particular value of $2s$. If the variations are small, $f(2s)$ is independent of r to the second order of small quantities. The form of the graph will depend upon the way in which r varies along the film.

From a powder photograph taken with a standard crystalline substance (K Cl) and Cu K α radiation, values of r for the smallest camera were calculated by direct application of Bragg's equation. 6·277 A was adopted as the edge of the unit cell of K Cl and 1·539 A as the wave-length of Cu K α. These values of r were found to vary uniformly along the film. In view of these variations and since the minimum value of $2s$ occurring in the K Cl diffraction pattern taken under these conditions is about 2·8 cm., Mo K radiation was substituted for Cu K α and another K Cl photograph taken in order to record

lines nearer the direct beam and so to extend the range of calculated r's. The total variation in r is small. It was apparent, however, since r could be calculated over a range of $2s$ common to both films that r varied from film to film. This variation from film to film was small ; no means was devised of eliminating it. A mean value of 2·80 cm. for r (allowing for variations along a film and from film to film) was adopted. It was found that this mean differed by less than 2% from any radius on any film within the range of $2s$ recorded on the clay films.

This mean value of r was used in evaluating log $f(2s)$, and the graph of log (d/n) and log $f(2s)$ was plotted for the K Cl powder photograph taken with Cu radiation. Values of log $f(2s)$ obtained from the Mo photograph and corresponding values of log [(d/n) ($\lambda_{Cu}/\lambda_{Mo}$)] were also plotted. [(d/n) ($\lambda_{Cu}/\lambda_{Mo}$)] is the value of d/n (fictitious) corresponding to a line (produced by Cu radiation) with the same $2s$ as a K Cl line produced by Mo radiation. $\lambda_{Cu}/\lambda_{Mo}$ was adopted as 2·167. The two graphs were linear but, in view of the variation of radius from film to film, not exactly collinear.

A mean graph was adopted as the final graph. In the case of an unknown line the procedure was to measure $2s$, calculate $f(2s)$ and from this graph to deduce d/n.

This graph applies to a film of mean radius of 2·80 cm. The approximately uniform variations of r along the film are taken into account in this graph except in so far as $f(2s)$ is in reality a function of r. The adoption of a fixed value for r (2·80 cm.) involves for a 2% variation in r referred to above, an error of from 2% to 1½% in the value of any d/n deduced from the graph over the range 10 A to 1 A.

The K Cl lines were sharp and the background relatively clear. The soil colloid lines were fairly diffuse and the scattered background fairly intense. Optical methods of measuring $2s$ were unsatisfactory. A calibrated transparent millimetre scale was used for all but the very faintest lines ; in their case a metal scale was used. Measurements of $2s$ were made independently by both authors. For all but the faintest lines the maximum error in measuring $2s$ was considered to be 0·1 mm. This corresponds, over a range of d/n from 10 A to 1 A, to a range of error in d/n from 1% to zero respectively. For the very faintest lines the maximum error is larger.

Due therefore to variations in r and errors in $2s$ the total maximum percentage error in the case of all but the faintest lines varies from 3% in the vicinity of 10 A spacings to 1½% in the vicinity of 1 A spacings.

On some of the K Cl films taken with Cu Kα radiation the diffraction lines did not always appear simple. Some of the lines were accompanied by a faint satellite. The separation of the two was generally too large for the effect to be attributed to the α_1 and α_2 components and much too small to be attributed to the α and β components. It was not the same on different films on which the effect was observed, and moreover the effect appeared only with lines of large curvature. The satellite was always on the same side of the line as the centre of curvature. By suitable choice of film no error, it is believed, has been introduced by this effect. No explanation of the effect has been found.*

*The observed effect (at least as far as the inner lines are concerned) may be attributed to absorption of the radiation by the powder material (as suggested, in correspondence, by Dr. G. Nagelschmidt of the Rothamsted Experimental Station).

V. MEASURED SPACINGS AND INTENSITIES, WITH COMMENTS.

The value of d/n for every observable line in the powder photographs of the water dispersed sample of A 1351 (Cu radiation) and in the caustic soda dispersed sample of A 1351 (Cu radiation and Fe radiation) was deduced from the graph. In the case of the observed values of 2*s* on films obtained with Fe radiation, the graph gave $[(d/n)(\lambda_{Cu}/\lambda_{Fe})]$. d/n was therefore obtained by multiplying this quantity by $\lambda_{Fe}/\lambda_{Cu}$. The value adopted for this ratio was 1·257.

Powder photographs of the samples of A 1346 (water dispersed and caustic soda dispersed) taken with Cu radiation and with Fe radiation appeared to be identical (both with respect to spacings and with respect to line intensities) with corresponding photographs of the A 1351 samples. Measurements of 2*s* confirmed this. Values of d/n were not deduced.

In Table (1) are tabulated all observed values of d/n for the clay samples of A 1351. Intensities are estimated visually.

TABLE (1).

Interplanar Spacings of A 1351.

Line.	Intensity.	Water dispersed.	Caustic Soda dispersed.	
		Cu radiation.	Cu radiation.	Fe radiation.
1	m	10·27 A	10·15 A	10·44 A
2	m	7·26	7·26	7·12
3	v w	...	...	5·82
4	v w	4·97	4·97	4·91
5	v s	4·47	4·46	4·45
6	v w	4·17	...	...
7	m	3·56	3·56	3·54
8	m	3·31	3·31	3·33
9	w	...	3·03	3·02
10	w	2·86	2·84	2·82
11	s	2·57	2·56	2·56
12	d	2·39	2·41	2·38
13	v w	2·16	2·10	2·20 2·08
14	v w	1·97	1·97	1·97
15	v w	1·84	1·88	1·84
16	d	1·66	1·66	1·68
17	d			1·64
18	s	1·49	1·49	1·48
19	v w	1·44	...	1·42
20	v w	1·36	1·36	1·36
21	w	1·29	1·29	1·29
22	w	1·24	1·23	1·24

v s = very strong ; s = strong ; m = medium ; w = weak ; v w = very weak ; d = diffuse.

With regard to the use of Fe radiation, a definite resolution into two lines (16 and 17) was observed of what appears with Cu radiation to be one broad diffuse line. A doubtful resolution of line 13 was also observed (admitted by one observer only). Similar differences were observed with A 1346. Line 3 appears only with Fe radiation and (taking into account A 1346 and A 1351) with both water dispersed and caustic soda dispersed material. This

line (which is extremely faint) has not been indentified. Reference has already been made to the similarity of scattered background with both types of radiation.

The only observed difference between water dispersed and caustic soda dispersed material is in the case of A 1346 a reversal of intensity of lines 9 and 10. In the water dispersed material line 10 is more intense than line 9; for the caustic soda dispersed material the reverse is true. In A 1351 line 9 is absent in the water dispersed material and of similar intensity to line 10 in the caustic soda dispersed material. It appears that the effect of caustic soda treatment is to increase the intensity of line 9. This line (as will be seen in section VI) is attributable to a mica mineral.

VI. ANALYSIS OF X-RAY DATA.

The X-ray diffraction patterns of clay minerals are very much alike. The clay minerals however can be divided into three groups which can be fairly readily differentiated from one another:

(1) Kaolinite group (including halloysite, nacrite, dickite).

(2) Montmorillonite group (including bentonite, beidellite, nontronite).

(3) Mica group.

It has been pointed out* that each group is characterised by a particular large spacing, the approximate value of which is, in the case of—

(1) the kaolinite group, 7 A;

(2) the monmorillonite group, 15 A in the case of air-dried material;

(3) the mica group, 10 A.

These lines are not subject to confusion by the proximity of any others.

The diffraction pattern of group (1) minerals is largely destroyed by heating to 500° C; the pattern of group (2) is still present at 500° C (with a modification referred to below); and the pattern of group (3) is stable at all temperatures up to 500° C.

From inspection of Table (1) it is apparent that groups (2) and (3) are represented in the soil colloids examined. Since the soil colloid material had been air-dried (see section IIB) the absence of a line in the region of 15A indicated the absence of any clay mineral of group (2).

In order to establish that the spacing characteristic of the montmorillonite group could be recorded, a sample of bentonite was obtained from the Geology Department of the University of Western Australia. Its diffraction pattern showed a very strong line at 12·9 A. As this value indicated that the sample was partly dehydrated, some material was moistened and air-dried. The diffraction pattern then showed a very strong line at 15·1 A. This reversible behaviour of the montmorillonite lattice was first observed by Hofmann *et al.*† The strength of the 15·1 line was such that if only a relatively small quantity of a group (2) mineral were present in the soil samples, the line should be easily detectable above the scattered background.‡

In order to obtain further evidence as to the mineral constituents of the soil colloids, and also with the object of assigning an origin to all our recorded lines, all the observed interplanar spacings as given in Table (1) were compared

*See, for example, Kelley and Dore, Soil Sc. Soc. Proc., 1937, p. 115.

†Zeit. f. Krist., 86, 340, 1933.

‡Since this report has been completed a clay fraction from the Huon Valley in southern Tasmania has been examined. In its diffraction pattern a 15 A line is readily detectable.

with published data relating to pure clay minerals. No data is known for any Australian clay minerals. From this data lists of spacings were drawn up for each of the following three pure minerals representative of the three groups of soil colloids : kaolinite, montmorillonite, and muscovite. Only lines of medium or higher intensity in the X-ray patterns of the pure minerals were included in each list, it being assumed that the faintest lines in the pattern of a pure mineral may not appear, for various reasons, in the pattern of a clay colloid containing the mineral. Since corresponding lines showed differences from observer to observer (both with respect to spacing and with respect to intensity) a mean intensity and a mean spacing were adopted for each line where corresponding lines from observer to observer could be definitely identified. In the drawing up of these lists all the relevant data that appears in the following published works was used : Nagelschmidt (Zeit. f. Krist. 87, 120, 1934) and Favajee (Zeit. f. Krist. 100, 425, 1939). In Table (2) are tabulated the mean interplanar spacings of A 1351. A plus sign in one of the last three columns indicates an agreement (to within 3% in the case of line 1 and to within less than 3% in the case of the remaining lines) between the value of a spacing obtained experimentally for the soil colloids by the authors of this paper and a spacing obtained from published data for one of the three representative minerals.

TABLE (2).

Comparison of A 1351 *with Published Data.*

A 1351			Kaolinite.	Montmorillonite.	Muscovite.
Line.	Intensity.	d/n in A.			
1	m	10·29	—	—	·
2	m	7·21	+	—	—
3	v w	5·82	—	—	—
4	v w	4·95	—	+	+
5	v s	4·46	+	+	+
6	v w	4·17	+	—	—
7	m	3·55	+	—	—
8	m	3·32	—	—	+
9	w	3·02	—	+	+
10	w	2·84	—	—	+
11	s	2·56	+	+	+
12	d	2·39	+	—	+
13	v w	2·13	—	—	+
14	v w	1·97	+	—	+
15	v w	1·85	—	—	—
16 ... ... 17	} d	1·66	+	+	+
18	s	1·49	+	+	+
19	v w	1·43	—	—	—
20	v w	1·36	—	—	+
21	w	1·29	—	+	+
22	w	1·24	—	—	—

v s = very strong ; s = strong ; m = medium ; w = weak ; v w = very weak ; d = diffuse.

All the lines listed (from published data as described above) for kaolinite, montmorillonite, and muscovite have been fitted into Table (2), except the strong montmorillonite line at 15 A (the absence of which has already been discussed) and a medium kaolinite line at 2·29 A. This line may be one

of two into which line 13 was doubtfully resolved with Fe radiation, as described in the previous section. It may be seen from the table that whereas no soil colloid line that can be assigned to montmorillonite may not also be assigned to one or both of the other two minerals, there are several instances of soil colloid lines that can only be assigned to one or both of kaolinite and muscovite. These facts provide further evidence in support of the conclusions reached from a consideration of the large characteristic spacings.

Lines 4 and 10 occur in the positions where the β line associated with lines 5 and 11 would fall. Intensity considerations lead to the conclusion that the β line, if present at all, is definitely not the sole contributor to lines 4 and 10.

A plus sign in only one column suggests that the line is characteristic of that particular mineral. This however may not be true for the reason that no account was taken of weak lines when the kaolinite, montmorillonite, and muscovite lists were drawn up.

Four lines have not been assigned any origin. Line 3 has already been discussed. Lines 15, 19, and 22 could have been assigned a possible origin if lines weaker than medium in the lists drawn up from published data had been taken into account. By a similar procedure further origins could have been assigned to lines 20 and 21.

With regard to non-clay constituents of the soil colloids, the possibility of quartz being present cannot be excluded in view of the appearance of a line in the position of the strong quartz line (3·34 A). From the non-appearance of a line at 2·69 A, haematite may be excluded. No opinion could be formed as to the presence or absence of geothite since the strong geothite lines correspond with lines of known different origin. A magnetic test with an electro-magnet revealed no magnetite.

Confirmation of these conclusions was obtained as a result of heat treatment. Some soil colloid material of A 1346 (water dispersed) was kept at about 500° C in air in an electric furnace for three days. The colour changed from greyish-yellow to brownish-yellow. The X-ray diffraction pattern showed a disappearance of line 2 (the characteristic kaolinite line at 7 A) and also of line 7. If weak mica lines are neglected, this line as well as line 2 is characteristic of a group 1 mineral. There appears in the region of line 7 a new line at about 3·72 A. In the absence of line 7 there was some evidence that a weak mica line at 3·48 A was discernable.

It would appear from Table (2) that line 12 should disappear on heat treatment. The line is rather weak and not sharp, and heat treatment has produced in the vicinity a change in the appearance of the pattern that could be explained by the disappearance of line 12 along with the exposure of a doubtful weak line of mica origin.

In the pattern of the heat-treated material line 8 at 3·32 A appeared relatively brighter than in the original pattern. This may be attributed to the appearance of quartz as a result of the destruction of kaolinite.

The pattern that remained after heat treatment (apart from differences just alluded to) was very similar to the original pattern. It is to be assumed that the pattern remaining is due to a mica mineral and that this pattern differs from the colloid pattern listed in Table (2) only in so far as it has been affected by the heat treatment in the manner described above. This pattern, assumed to be the mica pattern, has as its main character (apart from the

10 A line) a pronounced intensity of the 4·46 A line superior to the intensity of any other line. This character seems to differentiate the mica from any of the micas about which published data is available.*

Intensity considerations indicate that the mica mineral is far in excess of the kaolinite mineral in the colloid samples.

Evidence as to the percentage of mica in the clay may be obtained from chemical data. From the analytical data under IIC and on the assumption that the clay contains all the soil potash and that the clay mica here found contains 5% K_2O in which the K is non-replaceable, the clay separation from A 1346 contains 60% mica and that from A 1351 contains 50% mica.

A microscopic examination of the colloid material has been made and results will be published in a separate communication.

VII. SUMMARY.

A technique is described for obtaining X-ray diffraction patterns of crystalline substances (singly or in mixtures) in powdered form, and for deducing interplanar spacings from such patterns. From its application to soil colloid material the crystalline content of colloid separations from two soil samples from the Salmon Gums district in Western Australia designated as A 1346 and A 1351 (representing the subsoil and deep subsoil respectively) has been found to be the same for each sample and to comprise predominantly two clay minerals. One which is in excess belongs to the mica group and resembles illite ; the other belongs to the kaolinite group. Quartz may also be present in small quantity.

A comparison was made between the diffraction patterns obtained from two colloid samples prepared (from the same soil sample) by dispersion in distilled water and by dispersion in caustic soda respectively.

Chemical evidence indicates 60% mica in A 1346 and 50% mica in A 1351.

The results of a microscopic examination will be published in a separate communication.

VIII. ACKNOWLEDGMENTS.

The investigation was carried out in the Physics Department of the University of Western Australia during the tenure by one of us (W.F.C.) of a Commonwealth Research Grant for which the recipient wishes to express his thanks to the Council for Scientific and Industrial Research. The X-ray spectrograph and tube were originally provided by a grant from the same source. The authors appreciate very much the facilities that have been made available, through the Council for Scientific and Industrial Research, for carrying out the work.

Our thanks are also due to Dr. Teakle and Mr. Burvill of the State Department of Agriculture, and to Mr. Southern of the Government Chemical Laboratory, for their valuable assistance, and to numerous other colleagues who have been interested in the work.

*An article by Grim and Bradley (Report No. 53, State of Illinois Geological Survey, 1939) has recently come to our notice, in which X-ray data is published for a clay mineral of the illite group with the 10 A line of " medium " (as distinct from " strong ") intensity, agreeing in this respect with our own data.

12.—X RAY ANALYSIS OF SOME TASMANIAN SOIL COLLOIDS,

By J. SHEARER, M.Sc.* and W. F. COLE, B.Sc.

Read: 14th May, 1940; Published: 4th October, 1940.

In a previous publication (1) the authors have described a technique developed in general for X-ray analysis of crystalline material in powdered form, and in particular for the investigation of soil colloids. In this paper an account is given of the application of the technique to the study of soil colloid fractions prepared and supplied by Mr. C. G. Stephens, Research Officer in the Waite Institute, Adelaide, South Australia, whose interest led the authors to undertake the X-ray investigation of these samples.

The following particulars with regard to (a) the location of the profile from which the soil samples were obtained, (b) the method of separation of the clay fractions, and (c) analytical data with respect to soil samples and clay samples were kindly supplied by Mr. Stephens.

(a) *Location*: All four colloid samples from soils 222, 499, 551 and 560 come from Tasmania. Samples 551 and 560 are soil colloid fractions from soils obtained from Illawarra about 12 miles from Launceston in northern Tasmania, and 499 is from the basaltic soils of north-west Tasmania. These three samples are soil colloid fractions of soils which failed to grow good subterranean clover with the usual dressing of superphosphate. 222 is a soil from the Huon Valley in southern Tasmania, and is typical of large areas of podsolic soils which, responding readily to superphosphate, grow good subterranean clover.

(b) *Method of Separation*: The method of separation employed by Mr. Stephens was prepared by Mr. C. S. Piper of the Waite Institute. In this method (which was adopted as giving a clay more suitable for silicate analysis) separation is made according to the former British system in which the clay fraction has a settling velocity of 8.6 cm. in 24 hours. This clay ($1.4\,\mu$ and less) is finer than "International clay" ($2\,\mu$ and less).

The soil is boiled in water and 5N NaCl solution is added. After standing the clear supernatant liquid is decanted and discarded. The sandy constituent is separated from the residue with a 90-mesh sieve and discarded. 5N NaCl is added to the residue. It is then decanted twice at suitable intervals being refilled with water after the first decantation. A solution of ½N Na_2CO_3 is added to effect dispersion. Successive decantations and refillings to a depth of 8.6 cm. at 24-hourly intervals then follow, the refillings being first with water, then with Na_2CO_3 solution and finally with water again. When all the clay has been collected it is treated with ½N acetic acid. 5N $CaCl_2$ is added to produce flocculation. After standing the clay is filtered and finally washed with alcohol and oven-dried.

* Lecturer in Physics in the University of Western Australia.

(c) *Analytical data relating to soil samples and clay fractions:—*

MECHANICAL AND CHEMICAL DATA OF THE SOILS.

—	222.	551.	560.	499.
	per cent.	per cent.	per cent.	per cent.
Coarse sand (2·0—0·2mm.)	13·5	23·5	25·2	2·9
Fine sand (0·2—0·02mm.)	36·1	19·5	21·6	9·6
Silt (0·02—0·002mm.)	25·7	26·4	20·5	14·9
Clay (less than 0·002mm.)	19·4	23·7	25·4	51·6
Loss on acid treatment	1·6	2·5	3·5	10·8
Moisture	1·1	0·8	0·6	1·7
Loss on ignition	6·1	8·5	8·9	19·7
CaO requirement to pH 7·0	0·20	0·24	0·21	0·70
N	...	0·23	0·20	0·40
P_2O_5	...	0·14	0·16	0·15
K_2O	...	...	...	0·17
Reaction pH	5·1	5·8	5·7	5·4

CHEMICAL ANALYSIS AND MOLECULAR RATIOS OF CLAY FRACTIONS ($1 \cdot 4\mu$ and less).

—	SiO_2	Al_2O_3	Fe_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$
	%	%	%				
222	65·6	25·8	4·3	3·9	4·3	0·09	41
551	63·7	23·1	9·4	3·7	4·7	0·26	18
560	53·1	29·8	12·8	2·4	3·0	0·28	11
499	35·0	36·2	22·2	1·2	1·7	0·39	4

X-RAY ANALYSIS.

For experimental details, for details of the method used for determining interplanar spacings from measurements on the film, and for accuracy of results reference may be made to the earlier publication.

Copper (filtered) radiation was used with all four samples. In the case of sample 499, on account of the high iron content, it was found necessary to use iron (unfiltered) radiation in order to reduce the intensity of the background on the film.

In Table I. are tabulated all observed values of d/n for clay fractions 222, 560 and 499. The powder photograph of 551 was almost identical with that of 560 and consequently the photograph of 560 only was analysed in detail.

Commonly occurring minerals in soil colloids include the clay minerals, quartz and the oxides and hydroxides of Al and of Fe.

The clay minerals are recognised by taking into account the fact that they may be divided into three groups, each group being characterised by a particular large spacing, the approximate value of which is in the case of—

(1) the kaolinite group, 7 A;

(2) the montmorillonite group, 14-15 A for the air-dried material; and

(3) the mica group, 10 A.

These lines are not subject to confusion by the proximity of any other lines. In the absence of a mica, quartz is characterised by a line at 3.34 A which is the strongest quartz diffraction line. The kaolinite group comprises kaolinite, anauxite, nacrite, dickite, halloysite and hydrous halloysite. The montmorillonite group comprises montmorillonite, beidellite, nontronite and saponite. No subdivision of the mica group is at present recognised. The minerals within a group cannot readily be distinguished in a diffraction pattern of a soil colloid. In the remainder of the paper the terms "kaolinite," "montmorillonite" and "mica" will be used, for brevity, to designate a mineral belonging to the kaolinite group, the montmorillonite group and the mica group respectively.

TABLE I.

Interplanar spacings of soil colloids and assigned origins. (Filtered Cu radiation with 222 and 560; unfiltered Fe radiation with 499).

222.			560.			499.		
Intensity.	d/n.	Possible Origin.	Intensity.	d/n.	Possible Origin.	Intensity.	d/n.	Possible Origin.
w	14·0	M	vw(?)	(1)15 (?)	(M)	s	7·20	K
w	7·26	K	m	7·26	K	m	4·84	β line (2)
m	(3) 4·54	MK	s	4·46	(M)	s	4·42	K
vs	4·15	KQ		4·05	KQ	s	4·12	K
m	3·72	?	w	3·66	?	m	3·54	K
s	3·32	Q	w	3·54	K	w	3·31	Q
w	2·57	MKQ	s	3·32	Q	vw	2·98	?
	2·43		vw	2·66	H	d	2·80	H
w	2·34	K	d	2·56	(M)KQH		2·65	
w	2·27	KQ		2·41		d	2·55	KH
	2·22			2·11			2·47	
vw	2·12	Q	w	1·96	KQ		2·31	
w	1·97	KQ	vw	1·87	KH	d	2·17	?
m	1·80	Q	m	1·80	Q	vw	1·97	K
d	1·65	MKQ	d	1·66	(M)KQH	w	1·82	H
m	1·53	Q	m	1·53	Q	d	1·67	KH
m	1·48	MK	m	1·48	(M)KH	vw	1·63	K
vw	1·44	KQ	vw	1·45	KQH	m	1·47	KH
m	1·37	Q	m	1·37	Q	d	1·44	H
vw	1·32	K	vw	1·32	K		1·41	
vw	1·28	MQ	vw	1·27	(M)Q	...	...	...
d	1·23	MKQ	d	1·23	(M)KQ	...	...	...
w	1·20	Q	vw	1·19	Q			
w	1·17	Q		1·17		...	...	...
vw	1·14	Q	vw	1·14	Q	...	...	...
vw	1·07	Q	vw	1·07	Q	...	...	...
vw	1·04	Q	...	...	...	...	...	...
vw	1·01	Q	...	...	...	...	...	...
vw	0·91	Q	...	...	...	...	...	...
vw	0·88	Q	...	...	...	...	...	...

vs = very strong; s = strong; m = medium; w = weak; vw = very weak; d = diffuse.

M = Montmorillonite; K = Kaolinite; Q = Quartz; H = Haematite.

(1) A faint suggestion only of this line appears. Not confirmed by heat treatment.

(2) The value of d/n obtained on the assumption that this is the β line is 4·39A.

(3) This is the inner adge of a line that extends to the next line centred at 4·15A.

Brackets imply measurements of the inside and outside edges of a broad line (or lines).

The two unidentified lines in 499 could be associated with medium lines in the diffraction pattern of a mica. This is not inconsistent with the rest of the observed pattern of 499. The absence of the characteristic mica line has already been referred to.

On the basis of these characteristic lines, 222 was found to contain quartz, kaolinite and montmorillonite; 551 and 560 contain quartz and kaolinite with a possible trace of montmorillonite; 499 contains quartz and kaolinite. On the same basis there was no evidence of the existence of a mineral of the mica group in any of the clay samples.

In the previous Table I. are listed all the recorded lines for each clay sample with the assigned origin for each line. The data relating to the clays and to quartz were taken from Nagelschmidt (Zeit. f. Krist., 87, 120, 1934) and from Favajee (id. 100, 425, 1939). Where a recorded line could be identified with a line of medium or higher intensity as listed in the published data, a line with the same spacing in the pattern of another mineral was neglected when its intensity was less than medium.

The recorded lines were also examined with a view to obtaining evidence of the existence or non-existence of any of the oxides and hydroxides of Al and of Fe. For this purpose data supplied by Hanawalt, Rinn and Frevel (Ind. & Eng. Chem., Anal. Ed., 10, 457, 1938) was used. The only mineral of this group whose existence could be established was haematite. The four strongest haematite lines in order of decreasing intensity are 2.69 A, 2.51 A and (of equal intensity) 1.84 A and 1.69 A. Haematite is presumed to be present in samples 560, 551 and 499. No quartz or clay lines occur in the vicinity of 2.69 A. The strongest gibbsite ($Al_2O_3.3H_2O$) *line occurs at 4.88 A. In sample 499 a line appears at 4.84 A (assigned in Table I. to β radiation). From intensity considerations one cannot exclude the possibility of gibbsite being present in small quantity in this sample. From the X-ray evidence no opinion could be arrived at with regard to the presence or absence of any other mineral of this group. A magnetic test with an electro-magnet indicated the existence of a weakly magnetic material in the above three clay samples.

In Table II. are summarised the final conclusions with regard to the composition of the clay fractions. All estimates of relative quantities of the different constituents are based on visual observation of line intensities. These estimated relative quantities may correctly indicate the actual relative quantities only if the ratio of the intensities of patterns of different constituents is equal to the ratio of the proportions of the constituents. This may not be true and may depart widely from the truth if quartz is one of the constituents since the diffracting power of quartz is markedly greater than that of any other clay mineral.

With a view to obtaining more evidence as to the existence or non-existence of any montmorillonite in 560 (and 551), 560 was heated in a furnace in air for a day at 500° C. The 15 A spacing of montmorillonite shrinks to 10 A as a result of such treatment. No trace of such a line was observed. The main effect upon the pattern was in accord with the almost complete destruction of kaolinite. Other effects noted were, firstly, the appearance of a broad diffuse line centring at about 5.2 A resembling a diffraction ring from a non-crystalline material. There is a faint trace of this "diffraction ring" in the pattern of 499, and perhaps also (but still fainter) in the patterns of the

* The diffraction pattern given by Hanawalt *et al.* and assigned by them to "bauxite ($Al_2O_3.2H_2O$)" agrees closely with the diffraction pattern assigned by Nagelschmidt (*Journ. Agri. Sci.* Vol. **xxix**, 490, 1939) to gibbsite. We have followed Nagelschmidt in this.

TABLE II.

Composition of the soil colloids.

Fraction.	Quartz.	Kaolinite.	Montmorillonite.	Haematite.
222	Much	Little	Little	...
551	↑ Much	Much	Possible trace	Very little
560	↑ Much	Much	Possible trace	Very little
499	Very little	Much	...	Little

Note:

(1) An arrow (→) indicates increasing amounts of quartz. A similar assessment with regard to kaolinite in 551, 560 and 499 could not be made.

(2) The possibility of the presence of gibbsite in 499 cannot be excluded.

other clay fractions, including that of unheated 560. Secondly, a prominent new line appeared at 3.74 A. This line appears in the pattern of 222. It has also been observed on another occasion (1) where it might be attributable to a decomposition product of kaolinite which the authors have not been able to identify.

A microscopic examination has been made and results will be published separately.

SUMMARY.

An X-ray analysis of four clay fractions (effective diameter 1.4 μ and less) separated from four different Tasmanian soil samples is described. Results appear in Table II.

Results of a microscopic examination will be published separately.

ACKNOWLEDGMENTS.

The investigation was carried out in the Physics Department of the University of Western Australia during the tenure by one of us (W.F.C.) of a Commonwealth Research Grant for which the recipient wishes to express his thanks to the Council for Scientific and Industrial Research. The X-ray spectrograph and tube were originally provided by a grant from the same source. The authors greatly appreciate the facilities that have been made available, through the Council for Scientific and Industrial Research, for carrying out the work.

Our thanks are also due to Mr. C. G. Stephens, Research Officer in the Waite Institute, South Australia.

REFERENCE.

(1) Shearer, J., and Cole, W. F., Jour. Roy. Soc. W.A., 1939-40, Vol. **xxvi.**, pp. 121-131.

13.—THE GEOLOGY AND PHYSIOGRAPHY OF THE MALKUP AREA,

By W. F. COLE and C. S. GLOE.

Read 11th June, 1940; Published 8th November, 1940.

CONTENTS.

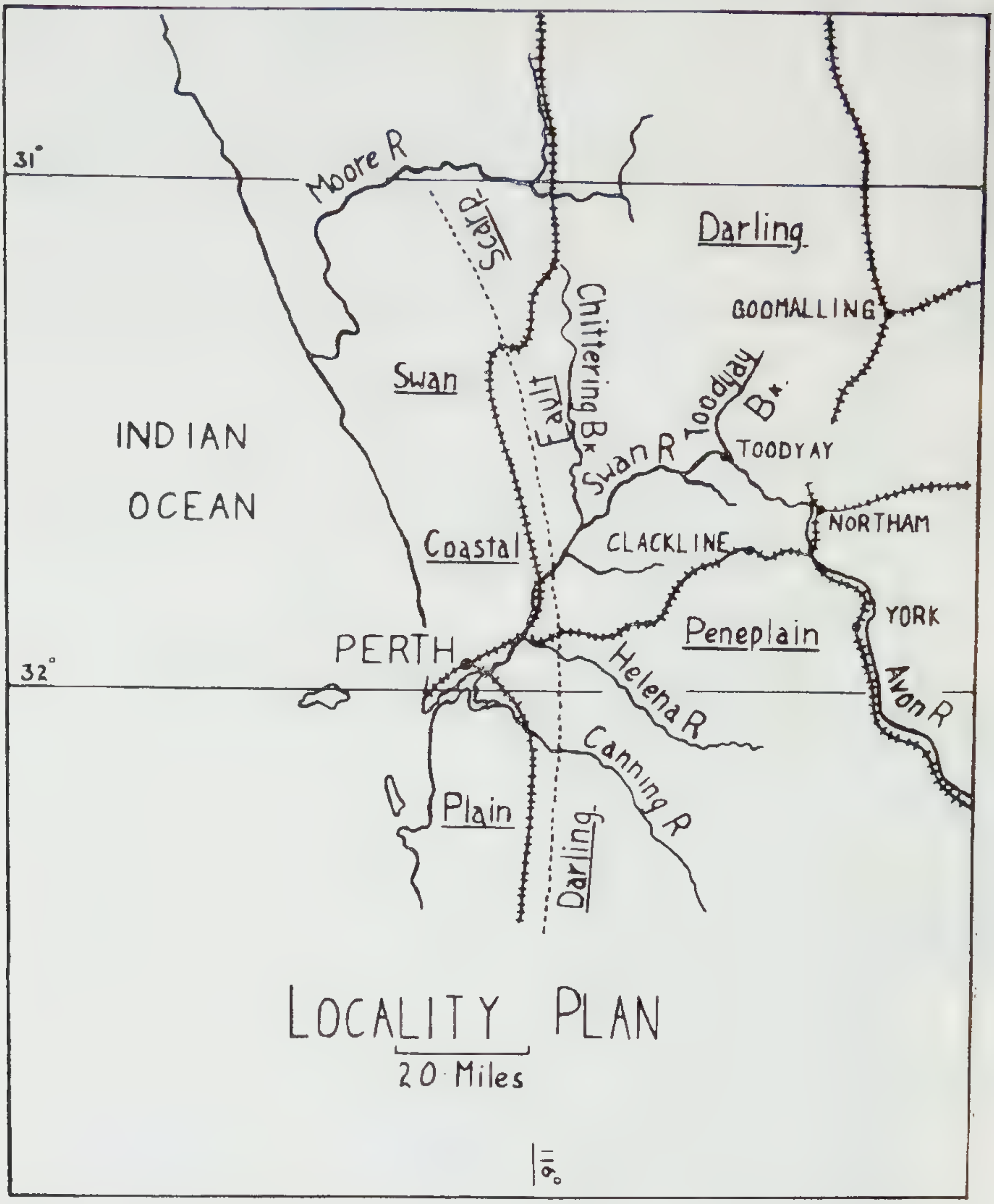

Fig. 1.—Locality Plan on which is shown the relative positions of the Swan Coastal Plain, Darling Peneplain, and Darling Fault Scarp (after Jutson).

I.—INTRODUCTION.

The Malkup Area is situated about 55 miles by road in a north-easterly direction from Perth and about 12 miles west of Toodyay (Fig. 1), and comprises part of the Pre-Cambrian complex. The southern portion of the area is joined on the east by the Jimperding Area, mapped by R. T. Prider (1934).

The area, which covers about ten square miles, lies in the South-West Land Division of Western Australia which may be divided physiographically into (Jutson, 1934, p. 84)—

1. The Swan Coastal Plain.
2. The Darling Peneplain and Darling Fault Scarp.

The Darling Fault Scarp which has been traced in a north-south direction for over 200 miles, rises sharply from the Swan Coastal Plain to an elevation of about 800-1,000 feet above sea level and forms the western edge of the Darling Peneplain. The Peneplain was once entirely covered by a laterite capping a few feet thick (Woolnough, 1918) but is now well dissected by rivers in various stages of maturity.

Erosion has disclosed two main groups of Pre-Cambrian rocks.

1. Metamorphosed sedimentary and igneous rocks of the Jimperding and Chittering series (R. T. Prider, 1934; K. R. Miles, 1938).

2. Igneous rocks of the Swan-Helena Type which consist of various granites (gneissic in places) with later doleritic intrusions (Clarke and Williams, 1926; Fletcher and Hobson, 1931).

Although the country around Toodyay was one of the first inland regions of Western Australia to be settled, the Malkup portion of the district has not progressed to any extent, owing to the poor soil, the rugged topography, and the discovery of more accessible and richer land to the east. The few inhabitants of the area derive their living from sheep farming.

Owing to the excellent gradient offered by the Avon River, from Northam to Perth, the Avon valley has been selected for a proposed Transcontinental Railway. When a preliminary survey was made in 1931 heights were determined at intervals of 1 chain along the proposed route and pegs inserted at every five chains. These pegs (the heights of which were obtained from the W.A. Government Railways) proved invaluable reference points for contouring.

As the area has been subdivided by the Lands and Survey Department, a detailed preliminary survey was not necessary. Most of the geological and topographical features were mapped by chain and compass traverses. The form lines were drawn from aneroid barometer readings working from the railway heights as data.

The greater part of the southern half of the area was mapped by the authors alone, but the northern half was mapped and contoured during the first term vacation of 1938 by the authors with parties of senior University students, under the leadership of Professor E. de C. Clarke.

II.—PHYSIOGRAPHY.

A. General Features.

The Malkup Area is a part of the drainage basin of the Swan-Avon River in which the river has cut deeply into the Darling Peneplain. The average height above sea level of the Avon Valley is about 350 feet, while the residuals of the peneplain (which cover about one-tenth of the surface area) are generally over 850 feet rising to a maximum of about 1,000 feet. On many maps this part of the Swan-Avon River is shown as the Swan River, but, in accordance with local usage, it will be referred to as the Avon in this paper.

According to Jutson (1934, p. 169) the Darling Peneplain was developed in Pre-Pleistocene times, and, later, rose to its present elevation, with the formation of the Darling Fault Scarp on its western edge. The effect of uplift was to produce a general tilt towards the south-east, initiating a new cycle of erosion in the form of consequent south-easterly flowing streams.

At the same time other more vigorous consequent streams were working back from the western coast. The west flowing streams ultimately, by headward erosion, captured parts of the south-easterly flowing streams.

The Avon River in the Malkup Area is part of the consequent western coast stream system which has captured, farther west, the waters of Chittering Brook and, just east of the Area, the waters of Toodyay Brook.

B. *The Avon River and its Tributaries.*

Within the Malkup Area the Avon River and its three main tributaries, Malkup, Mortigup and Munnapin Brooks, are all intermittent and in summer only the deeper pools of the Avon River contain water.

1. *The Avon River.*—The Avon River enters the Malkup Area near the south-east corner, flows slightly north of west for about two miles, then swings to the north in a broad arc which flattens out and turns south-west as the river leaves the Area. In this short distance there is thus little manifestation of the general south-west trend of the river.

On the whole the Avon Valley in the Malkup Area is intermediate in character between the broad mature valley at Northam and the gorge at Upper Swan (Fletcher and Hobson, 1931) where the river breaks through the Darling Fault Scarp. Indeed in the Area itself there is a gradual change from early mature in the eastern part of the valley to the more youthful cross-profile of the western.

The Avon Valley is asymmetrical in cross-profile throughout the Malkup Area. This asymmetry suggests a northerly migration of the river—a suggestion which is supported by the occurrence on the south side of the river of several "flights" of river terraces from 3 feet to 5 feet high and about one chain apart.

A flattened area, about ¾ mile south of the point where the Avon changes the direction of its course from north-west to south-west and about 500 feet above sea level, may possibly be correlated with Woolnough's high level river terraces which he terms the "Meckering Level." Such a level surface could be due (Woolnough, 1919, p. 390) to a small elevation subsequent to the formation of the Darling Peneplain and before its elevation to its present altitude.

A glance at the distribution of rock types in the Malkup Area, as shown on the geological map (Plate 1), does not reveal any explanation for the present course of the Avon River. As will be explained in a later section of this paper the structure of the Area is that of an anticline, the core of which is occupied by an intrusive granite gneiss. This weak structural unit offered to the Avon River, after its initiation by uplift of the peneplain in Pleistocene times, an easy path to base level. Since these times the metasedimentary series forming the upper part of the anticline has been removed and the intrusive granite gneiss of the core has been exposed. Time did not permit of an investigation into the structures developed in this gneissic core but later detailed surveys of this gneiss may indicate the existence of certain structures which may be correlated with the suggested anticlinal structure of the metasedimentary series and also with the present course of the Avon River. At present it is suggested that the Avon Valley in the greater part of the Malkup Area is an example of a superposed stream,

i.e., its course has been determined by the trend of a structural unit which has now been almost completely removed. The course of the Avon in the massive granite has been determined by the presence of main joint systems.

Pools on the upstream side of the mouths of the main tributaries except Mortigup Brook are characteristic of this part of the Avon. The average length of these pools is a quarter of a mile and their depth varies, but probably does not exceed 15 feet-20 feet. They appear to originate as a result of the damming back of the waters of the Avon River by the formation of a bar, at the tributary mouths, from sediment brought down by the flood waters of the tributaries.

2. *The Tributaries of the Avon.*—There is some evidence to suggest that the three main tributaries of the Avon River (Malkup, Mortigup and Munnapin Books) once formed part of a south-east drainage system which was later captured by headward erosion of the Avon. Malkup Brook may have once been continuous with the upper reaches of Mortigup Brook, and Munnapin Brook may have once represented another distinct system.

Malkup Brook.—According to the maps of the Lands Department on which its course is sketched, Malkup Brook flows south from its source for about 20 miles and enters the Avon River at about the centre of the Malkup Area. Except for the last mile, where, after being joined by a fairly large eastern branch, it flows due west, its course is most irregular. The few other tributaries are merely small subsequent streams whose profiles flatten out as they approach Malkup Brook. Although waterfalls are common in Malkup Brook the valley as a whole may be described as early mature because the cross-profile both above and below the falls is in keeping with this generalisation. In several places the stream has deposited considerable amounts of alluvium.

Munnapin Brook.—This stream lies in the north-west of the Area, and shows the dependence of the cross-profile on the type of underlying rock. Where the brook flows through granite it possesses a steep gradient accentuated by many small waterfalls but its valley becomes more mature where its course coincides with the contact of the granite and metamorphic series. Here, meandering across an alluvium covered flood plain, it has altered its course several times, as shown by the presence of "deserted bends." The eastern tributaries are rapidly dissecting the metasedimentary series but the western tributaries have as yet made little impression on the harder more resistant granite.

Mortigup Brook.—Mortigup Brook forms the main drainage system of the south-western portion of the area. The presence of a mature valley in its upper reaches suggests the possibility that Mortigup Brook was originally a south flowing stream, perhaps a continuation of Malkup Brook which has been captured and reversed by the Avon River. In its middle course Mortigup Brook is characterised by two sharp right angled bends which are due in both cases to well developed jointing in the granite. From here to its junction with the Avon River, the stream flows through an early mature valley with tributaries from the west actively dissecting the laterite capped plateau.

3. *Minor Features.*—Waterfalls occur only in the tributaries of the Avon River and are due either to vertical or horizontal joints or to very resistant basic dyke bars.

Springs are fairly numerous in the Area and are the only source of water during summer. They do not occur at any particular level, nor does any particular geological factor determine their origin. Many are at the contact of greenstone dykes and granite, but others occur scattered through the granite and gneiss.

Pot holes are common in the Avon River and its tributaries where they flow over granite. The largest noticed was five feet in diameter and five feet deep. They are usually quite symmetrical but unsymmetrical types occur.

C. Remnants of the Peneplain.

The remnants of the peneplain are the high laterite capped hills which are now being actively dissected by the headward erosion of the tributaries of the Avon River. The laterite capping is up to ten feet thick and occurs over all rock types in the area.

III. GEOLOGY.

A. Introductory.

The Area is essentially composed of metamorphic and igneous rocks, similar to those in the adjoining Jimperding Area, which are believed to be Pre-Cambrian in age (Prider, 1934). They are, in places, masked by the thin deposits of very recent age to which some reference has been made in the preceding section, where a general idea of their distribution is given.

This same belt of metamorphic and igneous rocks extends south-east from Jimperding to Clackline and thence to York (see Fig. 1 for localities). Another occurrence has been noted between Northam and Goomalling (Maitland, 1899, p. 28). The belt probably extends westwards from the Malkup Area to the Chittering Area (Miles, 1938), where it is represented by a series of very high-grade metamorphic rocks, which include kyanite, sillimanite and staurolite schists.

A glance at the geological map (Plate 1) shows that the Pre-Cambrian rocks fall into three groups—metamorphic rocks, granite and basic intrusives. The metamorphic rocks include metasediments which are exposed in the south-east and north-west, and gneisses, which are developed in the south-east, centre and east; the granite occupies the west side of the Area and sends out a wedge in a north-easterly direction; the basic intrusives form dyke-like bodies invading both the metamorphic rocks and the granite.

The prevailing trend of the metamorphic rocks in the south-eastern part of the Area is northerly, whereas in the north-western part it is easterly.

B. Field Characters and Distribution of the Pre-Cambrian Rocks.

1.—Metamorphic Rocks.

(a) *Metasedimentary Series.*

Mica-schist and Quartzite.—The main metasedimentary series in the south-east and north-west parts of the Area is made up of alternating beds of quartzite and mica schist. These rock types are also developed as small isolated patches in the granite of the west and in the gneiss of the north and north-eastern parts of the Area. Whereas in the south-east the beds strike north-west and dip at an average angle of 35° to the south-west, in

the north-west the strike is to the west and the beds dip at an average angle of 35° to the south. In the extreme north-west and north-east dips of 20°-45° to the north have been noted.

The quartzites are well bedded and weather into a flaggy rubble, which frequently obscures the softer schist formation. In many places they grade into mica schists. Lenses of quartzite in the schists are common.

Jasper Bars.—These rocks occur in the south-west corner as a narrow band overlying mica schist. Their occurrence is of particular interest because similar rocks have been described from the Bolgart Area north of Toodyay, where they occur as bands in the greenstones (Feldtmann, 1919, p. 27). Prider (1938, p. 62) has noted the occurrence of similar rocks in small xenoliths in granite gneisses in the Toodyay Area east of Malkup. The occurrence of similar rocks in the Goldfields Areas, where they are represented by banded quartz haematite rocks or "jasper bars," has been repeatedly noticed. The Malkup rocks show affinities to the rather rare eulysites.

(b) *Meta-Igneous.*

Basic Schists.—The basic schists are usually found inter-bedded with the mica schist and quartzite in the south-east, north-west and western parts of the Area. With one exception they occur as long thin bands difficult to trace in the field. They also occur as xenolithic patches in the granite and gneissic granite. Although all original textures and structures have been completely obliterated the basic schists appear to be original basaltic sills or flows which have been folded along with the meta-sedimentary series.

Granite Gneisses.—The granite gneisses may be subdivided into two groups according to the character of the felspar.

(1) *Biotite-microcline-granite gneiss.*—The authors have included under this division the broad band of augen gneiss on the south side of the river and the banded and slightly gneissic outcrops of the opposite side. The augen gneiss which directly underlies the quartzites of the south-east part of the Area, forms a prominent hill, the slopes of which are frequently broken by vertical cliffs (from 10-20 feet high). These cliffs are a result of the predominance of vertical joints in the gneiss. Towards its base the augen gneiss passes into a finely banded gneiss, the exposures of which continue on the north side of the river. This finely banded gneiss has, it is believed, resulted from a complete crushing of the augen in the augen gneiss. A gneissic granite or fluxion gneiss replaces the finely banded gneiss in the north and north-eastern parts of the Area. The fluxion gneiss is usually a rock possessing a faint linear parallelism of biotite flakes which passes into a granite showing crushing and cataclastic effects but no linear stretching.

(ii) *Biotite-oligoclase-granite gneiss.*—This rock type occurs as:—

(a) irregular patches in the fluxion gneiss of the north-eastern part of the area;

(b) an extensive development north of and along the middle and upper reaches of Malkup Brook. Here it is intruded by the microcline granite. The authors have not been able to find the field connection between (a) and (b), but because of their similar mineralogical composition they are conveniently treated together.

Xenoliths and Hybrid Rock Types.—In the biotite-microcline-granite gneiss there are xenoliths and irregular patches of more basic well banded gneisses, but no attempt has been made to map all the individual occurrences. In the north-east and eastern sections of the Area a more definite and extensive basification of the fluxion gneiss has taken place. Assimilation of basic igneous material comparable in composition with the basic schists, has produced a hybrid rock which, in mineralogical and textural features, is closely allied to the intermediate quartz-bearing plutonic igneous rock types.

In the biotite-oligoclase granite gneiss finer grained patches, more basic than the surrounding rocks frequently occur. Their general form is that of elongated spindles oriented parallel to the foliation of the surrounding gneiss. Sharp and regular contacts show that there has been little interaction between the two.

(c) *Doubtful Origin.*

Garnet Amphibolite.—This rock type occurs, just south of the mouth of Munnapin Brook, as a small band between beds of mica schist and quartzite. The rock is particularly interesting because of its occurrence in such an environment.

Comparison of the Metamorphic Rocks of Malkup Area with Jimperding Area.

The upper beds of the Jimperding Series continue into the south-eastern part of the Malkup Area. At Jimperding, Prider (1934, p. 6) noted the order given in Table I in the upper part of the conformable metamorphic series.

TABLE I.

Comparison of the Metamorphic Rocks of Malkup Area with Jimperding Area.

	Malkup Area.	
Jimperding Area.	South-east.	North-west.
Micaceous schist (upper most)—250′ Basic schist and gneiss 300-350′ No. 5 Quartzite—500′	Alternating series of mica schist and quartzite. One band of basic schist 30′ thick—2,000′-700′	Alternating series of mica schist and quartzite. No definite basic schist bands—2,600′
Upper Gneiss — 1,800′-1,900′	Augen gneiss—1,400′-0′	Not present

It is to be noted that, whereas the thicknesses of the different horizons are said to be fairly uniform throughout the Jimperding Area and the strike to be westerly with a southerly dip seldom exceeding 20°, as the beds are traced into the Malkup Area the thickness of the formations varies, the strike swings to the north-west, and the dip steepens to an average of 35° to the south-west. The augen gneiss (equivalent to Prider's Upper Gneiss) thins out towards the north-west and also in this direction the quartzites (equivalent to Prider's number 5 quartzite) overlying the augen gneiss are interbedded with a number of bands of mica schist on an average 100 feet thick. The basic schist and gneiss group is represented by a thin band of schist which follows the general strike of the metamorphic series. The metamorphic series of the south-east part of the Malkup Area are continued in the north-west where as has been previously noted the strike changes from north-west to west. Unfortunately the two parts of the Area are separated by a wedge of granite across which it is impossible to correlate the series. The general character and thickness of the series in the north-west part of the Malkup Area are indicated in Table I.

2.—Acid Intrusives.

The acid intrusives are represented by a microcline granite and its associated aplites, pegmatites, quartz veins and felspar porphyries.

Grey granite similar to that of Jimperding and of the Darlington Area (see locality map Plate I.) occurs in the west and extends across the Avon in the form of a wedge to separate the north-west from the south-east. The actual intrusive contact of the granite and metamorphic series has not been observed but the frequent occurrence of the metamorphics as xenoliths in the rock, which has been identified microscopically as a granite, leaves no doubt as to its intrusive character. In the south-east part of the Area the boundary between the metamorphic series and the granite follows the strike of the metamorphics, but this is not the case for the remainder of Malkup Area. The granite outcrops form characteristic tors, sloping rock floors, cliffs and waterfalls. The last named are due, as mentioned above, to strong vertical joints.

Aplites, pegmatites, quartz veins and felspar porphyries are all intrusive into the granite and metamorphic series. The precise relationships between these last phase products of the granite magma have not been determined.

3.—Basic Intrusives.

The basic intrusives which are younger than the granitic rocks, are represented by dolerite, quartz dolerite and epidiorite.

As at Jimperding the basic intrusives have a predominant regional northerly trend. This is particularly noticeable in the western part of the Area where the dykes scarcely deviate from a north-south line. As no examples were found of dykes cutting through each other it has been assumed that they all belong to the same period of intrusion.

Xenoliths in the Quartz Dolerite.—The occurrence of xenolithic bodies in the quartz dolerite was noticed in two places. Firstly in a basic dyke cutting through granite west of the shear zone on the northern side of the Avon River and secondly in a basic dyke about a quarter of a mile north of the mouth of Malkup Brook. These xenoliths are of particular interest because they give some indication of the position of the original basic magma reservoir. This matter receives further attention in the petrographic section.

Associated Granophyres.—In the north of the south-east part of the Area a fairly large basic dyke cuts through both the granite-meta-sediment contact and, near that contact, has assimilated the country rocks, in particular, the granite. The result has been the production of a thin band of granophyre around the dyke. A similar rock type is also found where quartzite xenoliths occur in the above dyke. This occurrence of a granophyric margin on quartzite xenoliths would appear to resemble the micropegmatitic margins on quartzite xenoliths at Colonsay, where an ultra basic magma, now practically represented by hornblendite has engulfed xenoliths of quartzite (Reynolds, 1936). Two further occurrences of granophyre noted, were rather small local features, both due to a dyke marginally modifying the granite.

C. Structure of the Pre-Cambrian Complex.

1.—Structures Peculiar to the Metamorphic Rocks.

The general swing of the strike of the metamorphic rocks from west to north-west and back to west, passing from Jimperding through the south-east to the north-west part of the Malkup Area has already been noted.

The east-west strike of the patches of metamorphic rocks in the north-west and north-east parts of the Area, with dips to the north, suggests a possible anticlinal structure for the Area. Unfortunately outcrops of meta-sediments in the north part of the Area are scarce and not much reliance can be placed on dips and strikes of isolated patches. If the suggested structure is correct then the meta-sediments occurring along the arch of the anticline have been removed and a core of intrusive granite gneiss has been exposed. More work farther north of Malkup Area will have to be carried out before the structure will be made clear.

Minor folding in the meta-sediments, particularly the quartzites, is frequently noticeable and occasionally good drag folding occurs. Several readings of drag folding in quartzites above the augen gneiss were made and it was found possible to determine the position of these parts relative to a major structure. Readings indicate the western limb of an anticline overturned to the north-east. This is in keeping with the suggested major structure.

2. Later Fault Zone.

A remarkable brecciated zone occurs about half a mile from the western edge of the Area. Although it has been mapped for a distance of 3 miles in a gently sinuous north-south line a true idea of its width is only obtained where it is cut through by the Avon River and Mortigup Brook, because elsewhere it is obscured by steep talus slopes. To the north it dies out and to the south it disappears beneath laterite. Although the zone forks where it crosses the Avon River only one branch is found on the north side of the river.

The zone appears to be later than the basic dykes of the Area because a rather characteristic platy dyke is found on the east side of it in the south and on the west side of it in the north. Furthermore no dykes are seen to traverse it.

It consists essentially of brecciated granite which has been extensively injected by quartz veins (up to 2 inches wide). Although no actual displacement can be proved (as the zone is confined to granite) the authors consider it to be a shear or fault zone. Prider (1934, p. 5) has recorded a similar fault breccia from the Jimperding Area.

D. Later Rocks.

The later rocks consist of:—

(a) a superficial capping of laterite;

(b) deposits of alluvium on the flood plains of the Avon and its major tributaries.

(c) talus slopes of quartzite, dolerite and laterite on the steeper hill slopes.

It will be noted from the geological map (Plate I.) that except for the occurrence of a number of small plateau residuals on either side of the Avon River in the central part of the Area, the superficial capping of laterite is limited to the extreme edges of the Area.

Reference to the later rocks has already been made in the section on Physiography.

IV.—PETROGRAPHY.

A. *The Metamorphic Rocks.*

The metamorphic rocks of Malkup Area have been classified as follows:

1. Meta-Sediments.
2. Meta-Igneous.

1. Meta-Sediments.

These have been subdivided into:—

(a) Mica Schists.
(b) Quartzites.
(c) Jasper Bars.

(a) *Mica Schists.*—The following types are found, indicating that many different grades of metamorphism are present in the mica schists:—

Chlorite-sericite schists.
Biotite and muscovite schists.
Andalusite-mica schists.
Garnet-andalusite-mica schists.
Staurolite-mica schists.
Sillimanite-mica schists.

Chlorite-sericite schist marks the lowest grade of metamorphism. The rock type consists of bands of chlorite and sericite, alternating with quartz-felspar bands. The small pale green, pleochroic, chlorite laths show a stellate arrangement, whereas sericite forms small colourless scales disseminated throughout both chlorite and quartz felspar bands.

Biotite-muscovite schists are dark brown iron stained rocks. They possess a marked fissile structure, due to the parallel alignment of mica flakes.

In thin section the texture is granoblastic, gneissic, seriate. Muscovite is dominant over biotite and differs from it as regards degree of crystallinity. The deep reddish brown biotite crystals are usually more irregular in form and frequently show sagenite webbing (due to minute acicular crystals of rutile) as well as pleochroic haloes around zircon inclusions. Both micas are set in a quartz-felspar mosaic.

Specimen (17534, section 40579),* a highly contorted and dragfolded schist carries patches of epidote with much haematite. The epidote is slightly pleochroic from colourless to yellow green and has characteristic flecked interference colours. These patches may represent limy intercalations in the sandy argillaceous sediment or some original detrital pebbles.

Andalusite-mica schists represent that grade of metamorphism most extensively reached by the mica schists. They closely resemble those recorded from Jimperding but differ in the more ragged form of the andalusite crystals, which have been changed by retrograde metamorphism into a shimmer aggregate of sericite (Knopf, 1931). In thin section the colourless sericitised andalusite porphyroblasts are seen to enclose diablastically numerous small blebs of quartz presumably picked up during rapid crystal growth. Small brown tourmaline crystals occasionally occur.

* The figures in parentheses refer to catalogued specimens in the General Collection at the Geology Department, University of Western Australia.

Garnet-andalusite-mica schist, a local development of the andalusite-mica schists in the south-east part of the Area is very similar to the occurrences at Goyamin Pool, north of the Lower Chittering Area. Heavy mineral fractions show abundant small pink garnets (0.5 mm. diameter) of a composition presumably close to almandine. They indicate the attainment of higher grades of metamorphism locally.

Staurolite-mica schist (?) was recorded along the eastern branch of Malkup Brook. It is a greyish brown, rather weathered, fissile rock, with an uneven surface due to the presence of small dark crystals which resemble staurolite. However in thin section the positive identification of this mineral as staurolite is impossible because of its complete sericitisation.

Besides those minerals common to the mica schists, there occur also a few small grains of brown tourmaline, some of which are somewhat rounded. This tourmaline may be of pneumatolytic origin (from the granite intrusions) or an original detrital constituent of the sediment.

Sillimanite-mica schists represent the highest grade of metamorphism attained in the pelitic sediments. The sillimanite forms fine needle like aggregates sometimes inclined to stellate arrangement. The silky lustre of these aggregates serves to identify sillimanite provisionally in the hand specimen. As a result of retrograde metamorphism the sillimanite has given rise to sericite. The sillimanite has formed from both biotite and muscovite but as the generation from biotite requires alumina from the muscovite (Tattam, 1929) it is considered that the latter mineral has been the main source of sillimanite. Quartz crystals, containing unoriented needles of sillimanite, are common.

(b) *Quartzites.*—The quartzites vary considerably as regards grain size and texture and both along and across the strike. Although composed predominantly of quartz many quartzites show the development of small colourless flakes of sericite or muscovite along bedding planes. In others the greenish mica, chrome muscovite is well developed. With the development of considerable quantities of mica the quartzites pass into quartz mica schists (section 40611).

In thin section the quartzites show a granoblastic mosaic of interlocking crenulated quartz grains, throughout which are scattered granules and scales of different minerals. The occurrence of several micas has been mentioned previously. In one section (40533) the greenish chrome muscovite is much darker in colour and has a distinct pleochroism α = bright green, $\beta = \gamma$ = blue green. This may possibly be due to a higher chromium content. The micas (chrome muscovite, muscovite and biotite) occur as flakes between the quartz grains where they are usually in parallel orientation or as small rod-like inclusions in the quartz. Diopside was noticed in several sections. The mineral was of a distinct brown colour in the hand specimens, particularly on slightly weathered surfaces, but microscopic examination of fragments and thin sections revealed the true pale green colour. Other optical properties were $\gamma \wedge c = 42°$; optical character + ve. The hornblende of some quartzites may be due to close contact with dolerite dykes. Minor constituents noted in the quartzites include epidote (section 40631) as small yellowish green pleochroic granules; zircon as small subhedral crystals; apatite as small colourless rods; rutile (section 40611) as small dark brownish red subhedral crystals; and magnetite, haematite and possibly chromite (found only in the chrome muscovite) as very small grains.

(c) *Jasper Bars.*—The rock is characterised by a number of well defined layers some of which are highly contorted and drag folded. The contorted portion 4 cm. wide (fig. 2) is composed of ten bands of quartz from 2 mm. to 4 mm. wide alternating with fairly narrow bands (2 mm. wide) of iron ore. This drag folded portion is bordered by a series of layers of very dark brownish highly weathered material 5 mm. wide, alternating with thin bands of iron ore 2 mm. wide. In some cases the iron ore is replaced by bands of idioblastic blue green amphibole.

Fig. 2. *Jasper Bar*—Spec. (17521).—The quartz iron ore bands are represented in the centre of the figure bordered by amphibole iron ore bands (dotted), which contain dark bands of pure iron ore. The wide dark band between the quartz iron ore bands and the amphibole iron ore bands at the top, is composed of pure blue green amphibole.

In thin section the following minerals were recognised:—Quartz, iron ore, cummingtonite and a blue-green amphibole. The clear xenoblastic quartz crystals show undulose extinction, and are often present as inclusions in the iron ore, which occurs as irregular aggregates and grains frequently segregated into bands. A simple test with a magnet indicates that the greater part of the iron ore is magnetite. Its streak is brownish black. This colour is due to the magnetite being partly replaced by an iron sesquioxide. Elongated sections of the idioblastic blue-green amphibole show parallel cleavage and basal sections show typical amphibole cleavage. The optics of the amphibole are: Pleochroism α = yellow, β = black, γ = light blue; $\gamma \wedge c = 15°$; $\gamma > 1.706 > \alpha$. Inclusions are rare and the crystal faces are often stained with iron oxide. The blue-green amphibole is usually xenoblastic towards the cummingtonite, which shows both parallel and intersecting amphibole cleavage. The optical character of this variety of cummingtonite is —ve and the extinction $\gamma \wedge c = 10°$. Simple twinning is common and traces of inclusions of blue-green amphibole are often present. Other bands show the existence of a minute striation parallel to the basal

plane. Where this is combined with the common prism cleavage a characteristic type of herring bone appearance is produced. The + ve optical character of this mineral which has $\gamma \wedge c = 16°$ and $\gamma = 1.67$, indicates a variety of cummingtonite with approximately 40 Mol.% $FeSiO_3$ (Winchell, 1927, p. 206). The — ve optical character of some types noted above may be due to the admixture of the actinolite molecule (Prider, 1938, p. 66).

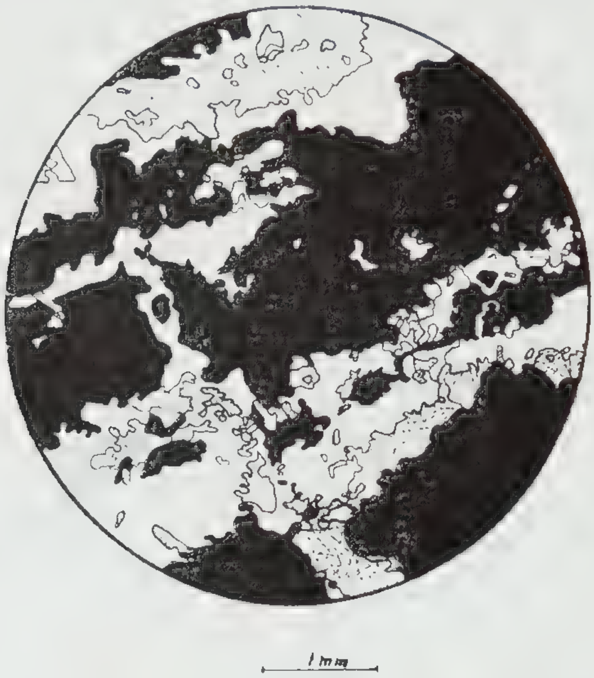

Fig. 3. *Jasper Bar*—Section (40535).—Quartz iron ore bands. Shows banded nature of quartz and iron ore with small cummingtonite crystals projecting from the iron ore.

Under the microscope the different bands which can be recognised are:—

(1) Quartz-iron ore bands;

(2) Amphibole-iron ore bands which alternate with either,

(a) pure blue green amphibole bands;

(b) pure iron ore bands.

(1) (Fig. 3). The quartz bands are 1 mm. wide and alternate with iron ore bands 2 mm. wide. While the trend of the iron ore bands is fairly constant, their edges are frequently broken by inclusions of quartz. The regularity is also destroyed by the projection of cummingtonite crystals from the iron ore bands into the quartz bands. The unoriented cummingtonite crystals are in the form of small rods which possess a somewhat fibrous structure.

(2) The very highly weathered brownish bands occurring outside (1) above are composed mainly of amphibole and iron ore. The texture is granoblastic gneissic, the constituent minerals forming an interlocking equigranular mosaic. The cummingtonite crystals are never more than $\frac{1}{5}$ mm. long and often show patches of blue-green amphibole. The iron ore usually forms irregular granules and the crystals of blue-green amphibole are usually smaller than the cummingtonite crystals. Some sections show this layer to be composed almost entirely of cummingtonite, with only a few scattered crystals of blue-green amphibole and no iron ore.

(a) The boundary between the pure blue-green amphibole band and (2) above is well marked. The band is 4 mm. wide and is characterised by the development of large idioblastic crystals of blue-green amphibole (4 mm. x 2 mm.) to the exclusion of all other minerals (Fig. 4).

(b) The iron ore bands alternating with (2) above are essentially similar to the iron ore in (1) above.

Fig. 4. *Jasper Bar*—Section (40535), showing junction of large blue green hornblende band with an amphibole iron ore band which is composed of cummingtonite (dotted), blue green amphibole and iron ore.

2. Meta-Igneous.

These have been subdivided into:—

(a) Basic schists.

(b) Granite gneisses.

(a) *Basic schists (Hornblende schists)*.—The basic schists are characterised by the presence of hornblende, felspar and a little quartz. The colour of the hand specimens vary from dark greenish black to black and the texture varies from schistose to massive. Epidote veins are common.

Under the microscope the following minerals were recognised:—Hornblende, oligoclase, quartz, orthoclase, diopside and accessory apatite, ilmenite, epidote, sphene and zircon. The form of the hornblende varies with the character of the rocks. It may be decussate; xenoblastic with poeciloblastic inclusions of quartz or in the form of ragged plates or fibrous stout prisms oriented parallel to the schistosity. The optics of the hornblende are pleochroism α = yellow green, β = green, γ = blue green; extinction $\gamma \wedge c = 20°$; $\gamma > 1.66 > \alpha$. Prider (1938, p. 45) notes that hornblendes from the Toodyay hornblende schists have β 1.672, which is indicative of hornblende from epidiorites in the sillimanite zone. (Wiseman, 1934, p. 394). Both simple and multiple twinning occur and inclusions of xenoblastic quartz, granular

diopside, epidote, sphene (with associated pleochroic haloes), are common. The dominant felspar is slightly turbid oligoclase, which shows albite and pericline twinning. In one instance (section 40592) inclusions of long acicular hornblende crystals were noticed. Quartz and orthoclase are subordinate and apatite, ilmenite, epidote, sphene and zircon occur as accessories. The mineralogical composition (volume %) is variable. Hornblende 60-80%, felspar 20-40%, quartz 5%.

Narrow bands and lenticles of diopside were recorded in some hornblende schists. This mineral forms greenish blue to colourless equidimensional crystals, with the rectangular prism cleavages well developed. Extinction is $\gamma \wedge c = 30°$. It is idioblastic towards the plagioclase and contains poikiloblastic inclusions of quartz and felspar.

In specimens from the contact of hornblende schist with granite the hornblende has been heavily chloritised and this may explain the occurrence of small patches of chlorite schist in the granite. The chlorite schists are hard, massive, distinctly foliated rocks, possessing in thin section a lepidoblastic structure due to the presence of long irregular frayed bands of colourless to dark green chlorite. Epidote occurs scattered throughout the rocks either as columnar crystals or granular aggregates. Quartz forms clear colourless xenoblastic crystals easily distinguishable from the sericitised albite.

(b) *Granite Gneisses.*—The granite gneisses may be subdivided into two groups according to the character of the felspar.

TABLE II.

Micrometric Analysis of Granites and Granite Gneisses of Malkup Area.
Mineral Percentage by Volume.

Mineral.	1	2	3	4	5
Quartz	29.2	39.2	23.3	38.8	30.5
Potash felspar	35.8	27.8	40.5	44.8	9.8
Plagioclase	10.4	12.7	4.1	9.4	33.6
Microperthite	18.5	11.4	18.9	2.4	..
Myrmekite	1.0	..	1.8	0.6	..
Biotite	4.7	7.6	4.8	2.2	25.9
Magnetite	0.4	1.3	5.4	0.2	..
Epidote	..	..	1.2	1.6	..
Apatite	..	..	..	..	0.2

1. Microcline granite—section 40586.
2. Microcline granite—section 40678.
3. Biotite-microcline-granite gneiss—section 40538.
4. Biotite-microcline-granite gneiss—section 40663.
5. Biotite-oligoclase-granite gneiss—section 40549.

(i) *Biotite-microcline-granite gneiss.*

Augen gneiss.—The texture is medium to fine grained and in thin section the structure is granoblastic gneissic. Microcline, orthoclase, quartz, plagioclase and biotite form the essential minerals and epidote, apatite, muscovite, chlorite, magnetite and ilmenite the accessories. Where the edges of the large cracked microcline plates are in contact with plagioclase, myrmekitic intergrowths are often developed. The microcline crystals also contain irregular inclusions of quartz and plagioclase. Quartz occurs in xenoblastic unstrained crystals sometimes elongated parallel to the banding. Oligoclase is usually less abundant than microcline and is present as rather large saussuritised and sericitised unoriented crystals. Biotite forms greenish

brown deeply pleochroic crystals (α = yellow brown, β = γ = brown) aligned in more or less definite bands parallel to the foliation. The crystals show sagenite webbing, as well as pleochroic haloes around zircon inclusions. Alteration to chlorite is common.

The mineralogical composition (volume %) of the rock by micrometric analysis is given in Table II., column 3.

Banded acid gneisses.—Mineralogically these rocks resemble the augen gneisses but differ in the more complete granulation of the augen.

Prider (1938, p. 52) has noted the occurrence of xenolithic bodies, of both igneous and sedimentary origin, in the augen gneisses of the Toodyay Area. The igneous xenoliths include schistose plagioclase amphibolites and hornblende schlieren. The sedimentary xenoliths are biotite granulites, which are considered to be developed from psammitic sediments. Only one of these rather rare xenoliths has been noted in the augen gneiss of the Malkup Area. As these rocks though are undoubtedly continuous with those of the Toodyay Area, they must have the same origin.

Fluxion gneiss.—In thin section the fluxion gneiss differs from the augen gneiss in that the quartz crystals frequently show undulose extinction. The twin lamellae of the plagioclase crystals (oligoclase andesine) are also highly strained. (Incidentally the presence of myrmekite along with the deformed plagioclase indicates that it was formed after the shearing.) Further the dominant felspar is usually orthoclase showing alteration to microcline. This is recognised by the development of cross hatched twinning along the borders of the orthoclase crystals. There has been an increase in volume accompanying the change from orthoclase to microcline as revealed by undulose extinction and phantom twinning in central parts of the crystals. (Alling, 1923, pp. 283-305 and pp. 353-375.)

The mineralogical composition (volume %) of the rock by micrometric analysis is given in Table II., column 4. This rock type grades through a crushed microcline granite (section 40613) to the typical microcline granite of the western part of the Area.

(ii) *Biotite-oligoclase-granite gneiss.*—The rock is light to medium grey in colour, well banded, and is cut by later aplites and pegmatites. Where finely banded the structure may become schistose.

In thin section the texture is granoblastic gneissic. The minerals present are oligoclase, quartz and biotite, with apatite, sphene and ilmenite as accessories. Oligoclase occurs as elongated subhedral grains oriented parallel to the banding. The crystals are turbid and many show zonal arrangement of inclusions, as well as blebs of quartz. Quartz, like oligoclase, is elongated parallel to the banding. Biotite, which occurs in bands, frequently possesses a clotted character indicating that it is probably a remnant of some earlier rock picked up by the intrusive granite magma, i.e., these clots of biotite may be micro-xenoliths. The biotite has frequently been altered to penninite.

The mineralogical composition (volume %) by micrometric analysis is given in Table II., column 5.

(c) *Xenolithic bodies in both Augen and Fluxion Gneisses.*

Pyroxene-amphibole gneiss.—This rock type only occurs in two localities; firstly as a narrow band in the augen gneiss and secondly as a few scattered boulders in the north-eastern part of the Area, the main rock type of which is a fluxion gneiss.

They are hard, massive, greenish rocks, slightly banded due to the alternation of quartz with greenish hornblende and diopside. Pyrite is present.

In thin section the texture is granoblastic gneissic with the minerals tending to form interlocking mosaics. Minerals present are quartz, microcline, orthoclase, plagioclase, hornblende and diopside with accessory pleochroic sphene, needles of apatite and zircon. The quartz is elongated parallel to the banding. Orthoclase forms anhedral plates frequently showing inversion to microcline with accompanying undulose extinction. Inclusions of rounded quartz blebs, apatite rods, diopside and hornblende crystals are common. The potash felspar is almost invariably turbid. Hornblende occurs as irregular plates and fibrous rods elongated parallel to the banding. The pleochroism is $\alpha =$ yellow green, $\beta -$ green, $\gamma =$ blue green, and the extinction $\gamma \wedge c = 23°$. A few idioblastic crystals of brownish hornblende occur. The hornblende is intimately associated with equidimensional grains of a colourless to green pyroxene which has extinction $\gamma \wedge c = 40°$.

(d) *Xenoliths and Hybridisation of the Fluxion Gneiss.*

The various stages in the progressive assimilation of basic rocks (mineralogically identical with the basic schists) by the microcline granite magma may be summarised as follows:—

Hybridised Types.

Basic Schist → { Melano-cratic → Meso-ratic → Leuco-ratic } → Fluxion Gneiss.

Within the hybridised types there are two distinct groups:—

(i) Rocks with granoblastic gneissic structure.

(ii) Rocks with granitic structure.

The basic schist and fluxion gneiss have been previously described (p. 153 and p. 155). The hybrid types are:—

(1) *Rocks with granoblastic gneissic structures.*—These may be called hornblende gneisses and they vary from melanocratic to leucocratic. The melanocratic hornblende gneiss which differs from the basic schist only in texture, contains hornblende, oligoclase and quartz, with accessory magnetite and apatite. The hornblende forms large porphyroblasts usually hypidioblastic with typical prism cleavages. The pleochroism is $\alpha =$ yellow green, $\beta =$ dark green, $\gamma =$ blue green, and the extinction is $\gamma \wedge c = 16°$. The form and optical properties of the amphibole are constant throughout the series. With an increase in felspar content and a corresponding decrease in the hornblende content the melanocratic hornblende gneisses pass into mesocratic hornblende gneisses. The increase in the felspar content is due to the addition of alkali felspar from the magma. The decrease in hornblende content is due to the instability of that mineral under the new conditions. Its alteration products are biotite, chlorite, epidote and sphene. The biotite forms irregular, ragged, weakly pleochroic flakes moulded on the hornblende. Patches of faintly pleochroic pale green chlorite ($\beta = 1.625$), which contain inclusions of lozenge shaped crystals of sphene and colourless to yellow granules of feebly pleochroic epidote, have resulted from the alteration of biotite. The oligoclase felspar is also unstable and has been replaced by a mat of sericite and granular epidote. The passage from mesocratic hornblende gneisses to leucocratic hornblende gneisses is a result of further increased felspar content and corresponding

reduced hornblende content. The reaction products from the alternation of hornblende and oligoclase are further increased. With the appearance of microcline, complete assimilation of the hornblende, and re-adjustment of the reaction products the leucocratic hornblende gneisses grade into the normal fluxion gneiss.

Fig. 5. *Hybrid*—Section (40643), showing crystals of sphene moulded on iron ore and containing chlorite inclusions which are in optical continuity with the chlorite in which the sphene is embedded. Epidote (E) enclosed in chlorite, hornblende (H) altering to chlorite, saussuritised felspar and quartz comprise the remainder of the slide.

(ii) *Rocks with Granitic Structure.*—Mineralogically, the hybridisation of the fluxion gneiss in the extreme eastern part of the Area is almost identical with (1) above. The rocks produced, however, show a complete lack of gneissic banding, basic segregations and clots. They are predominantly even grained, holocrystalline and uniform textured. However, the twin lamellae of many of the felspar crystals are often distorted and quartz crystals show undulose extinction. The occurrence of clinozoisite as euhedral crystals protruding from heavily saussuritised felspar (section 40640), and of sphene rims around iron ores (Fig. 5) are minor noteworthy mineralogical differences from the hornblende gneisses. As the fluxion gneiss is approached the hornblende content decreases, biotite increases and microcline replaces plagioclase.

(e) *Xenoliths in the Biotite-Oligoclase-Granite Gneiss.*

Biotite-plagioclase-granulite.—In thin section, biotite, the only ferromagnesian mineral, is seen to make up from 30-40% of the rock. The irregular, rarely chloritised plates show a pleochroism $\beta = \gamma =$ black, $\alpha =$ yellow brown. Plagioclase, the dominant felspar, forms about 35% of the rock. Clear colourless quartz crystals, which contain numerous rod-like inclusions of apatite oriented parallel to the gneissic banding, form an

interlocking mosaic with the xenoblastic felspar crystals. Accessories include a little magnetite, granular sphene, and zircon with its associated pleochroic haloes when included in biotite.

3.—Doubtful Origin.

Garnet Amphibolite.—The rock is dark greenish brown in colour, rather coarse grained, hard and massive with an uneven fracture and high S.G. (= 3.13). It is composed of pink garnet and greenish black amphibole. As a result of weathering it is slightly iron stained.

In thin section the structure is in part granoblastic and in part nematoblastic. The nematoblastic structure is due to a parallel orientation of the amphibole. Garnets occur in rather large equidimensional crystals (up to 5 mm. across) with poikiloblastic inclusions of quartz, amphibole and magnetite. Their surface has rather a pitted appearance and they are often altered along cracks to chlorite and magnetite. Garnet pseudomorphs after amphibole (cummingtonite) indicate the later formation of garnet with a composition very similar to that of the amphibole. Cummingtonite is present as light green to colourless slightly pleochroic crystals, generally showing good cleavage and positive elongation. Twinning is common and the optical character is +ve. The extinction is $\gamma \wedge c = 18°$ and γ lies between 1.686 and 1.691. This indicates a cummingtonite with 70 Mol. % $FeSiO_3$ (Winchell, 1927, p. 206). This mineral, which may form parallel or radiate growths, contains inclusions of quartz and colourless zircon. Its replacement by garnet has already been mentioned. Quartz occurs in clear xenoblastic interstitial crystals. Accessories include colourless rounded apatite, light brownish crystals of sphene and a little magnetite and chlorite.

B.—The Later Igneous Intrusions.

1.—Acid Intrusives.

(a) *Microcline Granite.*—The microcline granite, which occurs mainly in the western part of the Area, is a fine to medium grained, seriate, leucocratic, granitic textured rock. In composition it is very acid with a rather low percentage of ferromagnesians. The S.G. averages 2.63.

In thin section the following minerals were recognised:—

Quartz—abundant in all slides as anhedral, slightly cracked crystals of variable grain size. Interstitial growths occur with the felspars.

Felspars—Microcline and orthoclase are abundant in slightly turbid hypidiomorphic crystals. The turbidity is due to kaolinisation and sericitisation. Plates often show embayed edges carrying myrmekite and quartz. Oligoclase is present in most sections as saussuritised euhedral to subhedral crystals. The zoned arrangement of alteration products indicates a zoning in which the centres of the crystals are composed of a more basic oligoclase than the outside.

Microperthite is common in the granites. It is "streaky perthite" (Anderson, 1937, p. 60)—veinlets of albite crossing potash felspar. There is no twinning in the albite and the intergrowth trends at right angles to the cleavage of the orthoclase.

Myrmekite is seen as wart-like intergrowths in orthoclase, microcline and microperthite. Its occurrence in microperthite produces an intergrowth similar to Geyer's myrmekite perthite (Sederholm, 1916).

Injection micropegmatite is particularly abundant and passes through all types of felspar. The inclination to the orthoclase cleavage is, on the average, 110°, but it often forms irregular stringers. True micropegmatite is not very common but does occur (section 40589). The felspar is very cloudy and the quartz of the intergrowth is seen to be in crystallographic continuity with the quartz crystal upon which it has grown.

Biotite forms characteristic ragged crystals with pleochroism γ = dark brown, α = yellow. It is often changed to synantetic chlorite which is pleochroic from yellow green to dark green. Inclusions of zircon, with strong pleochroic haloes, occur both in biotite and chlorite. Sagenite webbing, due to dark needle like inclusions of rutile arranged in an interlaced web structure, is frequently present. Sagenite webbing has been recorded in the granites of Chittering (Miles, 1938, p. 28), and Upper Swan Area (Fletcher and Hobson, 1931, p. 28). It is probably due to heating of original biotite with the separation from it of its titanium content in the form of rutile. The sagenite webbing is sometimes found remaining in synantetic chlorite.

Biotite is often moulded on yellow green anhedral epidote crystals which are pleochroic from yellow green to colourless. Most of the epidote appears to have been introduced as later veinlets, as for example section (40683) where the crystals are columnar and perfectly euhedral.

Muscovite is rare but where present is almost invariably associated with biotite. In section (40683) it is moulded on and included in plagioclase crystals parallel to the cleavage. Inclusions of epidote are common.

Sphene is a variable constituent forming euhedral to subhedral, brownish, non pleochroic, highly refracting crystals. It frequently contains a core of ilmenite and the smaller crystals are often moulded on either biotite or chlorite.

Accessories include slender acicular prisms and stumpy basal sections of apatite, crystals of zircon and rutile embedded in biotite and occasional grains of iron ore. Ilmenite when present is invariably surrounded by leucoxene or sphene.

(b) *Aplites and Associated Pegmatites.*—These intrude the metamorphics and the granite. Macroscopically the pegmatites consist of coarse textured crystalline quartz and alkaline felspar. The felspar crystals are as large as 6 inches long and 2 inches wide, but the quartz crystals are usually smaller. Dark segregations are abundant, one being 3/10 inch in diameter and surrounded by a rim of limonite.

The aplites are light coloured, fine grained, equigranular granitic rocks bordered by pegmatitic phases. They consist of quartz, alkaline felspar, plagioclase and a little biotite and muscovite.

In thin section the texture is fine grained granitic. Clear colourless anhedral quartz crystals averaging 0.1 mm. in diameter form an interlocking mosaic with the felspar. Both microcline and orthoclase occur abundantly in slightly cloudy sericitised subhedral plates. Oligoclase is subordinate in cloudy, slightly saussuritised hypidiomorphic plates. Microperthitic intergrowths, both of streaky and of patchy types are common and they frequently show undulose extinction. Biotite, usually chloritised, occurs as an accessory.

Muscovite forms subhedral plates idiomorphic towards both felspar and quartz. Garnet occurs in section (40605) as highly refracting, slightly cloudy, colourless isotropic grains.

(c) *Quartz Veins.*—Small quartz veins clearly cutting across the metamorphics and through the granite and gneiss are of frequent occurrence. Very few large veins have been noted. The relation of the quartz veins to the pegmatite aplite intrusions is not clearly seen but some of the smaller veins seem to have preceded the aplites and pegmatites.

(d) *Felspar Porphyries.*—The felspar porphyries form narrow dykes which appear to be cut by both the basic intrusives and the shear zone. In hand specimen they are light greyish blue, fine grained, massive rocks.

The porphyritic texture is revealed in thin sections where phenocrysts of felspar and quartz are embedded in a fine grained ground mass. The felspar occurs in highly altered subhedral to euhedral crystals. Orthoclase, showing carlsbad twinning and extensive kaolinisation and sericitisation, is usually dominant over plagioclase but in some slides this is reversed. The plagioclase (oligoclase) is often almost completely saussuritised and kaolinised. Quartz phenocrysts occur as clear anhedral to subhedral crystals up to 1 mm. in diameter. Biotite, which forms very ragged flakes altering to synantetic chlorite, shows no marked distinction between phenocrysts and ground mass.

A microcrystalline, allotriomorphic, interlocking mosaic of quartz, orthoclase, plagioclase and biotite constitutes the ground mass. Secondary minerals include much epidote mostly of later introduction but also derived in part from the saussuritisation of plagioclase felspar. Sericite derived from the potash felspar is also abundant.

In one specimen phenocrysts of felspar up to 3 mm. in diameter were recognised in a light brownish ground mass which is cut by numerous irregular dark green stringers.

With the exception of the stringers the rock is in thin section essentially the same as the more normal felspar porphyries. The impression obtained from a study of the rock in thin section, is that it has been severely brecciated and the cracks have later been healed by veinlets of epidote. The character of the biotite and chlorite also call for some comment. The chlorite occupies many irregular stringers and patches which often contain small brownish green laths of biotite. These resemble xenoliths which have been picked up by the porphyry, incompletely digested and later stretched out into stringers.

2.—Basic Intrusives.

The basic intrusives have been subdivided into—

(a) Dolerites.

(b) Quartz Dolerites.

(c) Epidiorites.

These differences may be correlated with variations in the proportion of end stage quartz residuum and the degree of deuteric alteration of the pyroxene. (See Table III.)

TABLE III.

Micrometric Analyses of Basic Intrusives from Malkup Area.

Mineral Percentage by Volume.

Mineral.	1	2	3
Plagioclase	44.4	36.1	37.3
Augite	39.3	34.8	..
Uralite	5.1	19.8	29.5
Hornblende	1.4	..	9.9
Chlorite	1.9	2.7	5.8
Iron Ores	7.1	5.8	5.6
Biotite	0.8	..	..
Pyrite	..	0.9	..
Apatite	..	..	2.0
Quartz	..	Present	9.9

1. Dolerite—section 40649.
2. Quartz Dolerite—section 40570.
3. Epidiorite—section 40574.

(*a*) & (*b*) *Dolerites and Quartz Dolerites* may be conveniently treated together. They are melanocratic, massive rocks, generally equigranular but frequently showing small veins and segregations of a much coarser pegmatitic phase which is mineralogically the same as the rest of the rock. Black augite, cloudy felspar and occasional pyrite, are the only minerals recognisable in the hand specimen.

Fig. 6. *Dolerite*—Section (40649), showing typical ophitic relation between felspar and augite. The iron ore is surrounded by a rim of chlorite.

In thin section ophitic texture is always well developed (Fig. 6). The constituent minerals include pyroxene, plagioclase felspar, quartz, iron ores, amphibole, biotite and accessories. Pyroxene occurs as colourless to light brown, non pleochroic, subhedral to euhedral crystals. Cleavage is usually well developed in one direction but sometimes in two directions at right angles to each other. Schiller structure has often been noted. The extinction angles vary, *e.g.* $\gamma \wedge c = 0° - 45°$. In sections with oblique extinction

a biaxial figure is obtained but those with straight extinction give a pseudo-uniaxial figure. The optical character is always —ve. This indicates a monoclinic pyroxene with small axial angle such as enstatite augite or pigeonite (Barth, 1931). Several dolerites showed the cleavages of this pyroxene arranged in a more or less circular fashion with incipient fracturing. These crystals are built up of segments which extinguish separately. While the pyroxene crystals in the dolerites are fairly fresh, in the quartz dolerites alteration to fibrous green uralite is common. All stages of alteration are found and often this uralitisation is followed by chloritisation.

Plagioclase occurs in long columnar and lath shaped crystals ophitically intergrown with the pyroxene. Fine lamellae and simple carlsbad twinning are common and extinctions normal to the plane of the albite twin lamellae indicate labradorite. Saussuritisation and kaolinisation are common. Aborescent chlorite (from alteration of uralite) is often found along cleavages and fractures in the plagioclase.

Quartz is absent from the dolerites but forms up to 5% in the average quartz dolerite. It occurs either interstitially or as clear allotriomorphic crystals which contain apatite inclusions.

Iron ores take the form of large "skeletal" crystals of ilmenite which show alteration to leucoxene along crystallographic axes. Where in contact with felspar they are usually rimmed with greenish chlorite, and occasionally with synantetic sphene. Magnetite and pyrite are also present.

Amphibole.—Two varieties are present (1) the pale green fibrous uralite which has resulted from the alteration of pyroxene; (2) a brownish well crystallised hornblende with pleochroism $\alpha =$ brownish yellow, $\beta =$ brownish green, $\gamma =$ green. Although seen associated with uralite the hornblende has a primary appearance.

Biotite is present in the quartz dolerites as small irregular flakes frequently exhibiting sagenite webbing. It has a pleochroism $\beta = \gamma =$ dark brown, $\alpha =$ straw yellow.

Accessories include apatite as long needles and rods which show cross fractures; zircon, with its associated pleochroic haloes, as inclusions in amphibole, biotite and chlorite; epidote as narrow veinlets and as an alteration product of the saussuritised plagioclase.

(*c*) *Epidiorites.* The epidiorites have all originated from dolerites by deuteric processes the results of which have not always been the same. They differ from the dolerites in the complete uralitisation of the augite and the comparative abundance of quartz. Although the ophitic texture is usually lost they are essentially the end members of a series from dolerites to quartz dolerites that is, a series of increasing acidity.

In another group of meta-dolerites or epidiorites the deuteric processes are probably due to some late stage magmatic change where the volatiles and gases played an important role. These rocks, being apparently only phases of the basic intrusives, have a limited distribution.

In hand specimen they are massive, uniform textured rocks sometimes tending to show a linear parallelism of hornblende rods. Other minerals present include felspar and a little pyrite.

In thin section the texture is holocrystalline allotriomorphic. Amphibole porphyroblasts form anhedral plates with "sieve" structure due to microscopic inclusions of quartz. The twinning developed is both simple and

lamellar and the pleochroism of most varieties is α = yellow green, β = dark green, γ = blue green. The felspar is generally completely altered to granular epidote, zoisite, sericite and fibrous chlorite. Although actual identification is difficult the felspar appears to be a sodic plagioclase. Some sections show typical anhedral crystals of quartz with acicular inclusions of apatite. The felspar also contains similar apatite inclusions. Irregular crystals of magnetite and leucoxenised ilmenite form the iron ores.

(*d*) *Xenoliths in the Quartz Dolerites.* Two types of basic intrusives rather different from the above have been observed. The first (17574, section 40584) was a basic dyke cutting through granite west of the shear zone on the northern side of the Avon River. From a distance it had a peculiar speckled appearance and on close examination this was found to be due to the presence of large angular slightly pinkish "minerals" scattered liberally through the rock. The size of these fragments ranges up to 1½ inches x 1 inch. They are generally quite idiomorphic although occasionally aggregates of fragments are seen as though partially digested by the magma. A section cut across the contact of an idiomorphic crystal with the dark fine grained "ground mass" showed the latter to be composed of epidiorite with one or two small remnants of augite. The uralite is largely altered to chlorite and sometimes subophitically encloses a little plagioclase. Interstitial quartz and micropegmatite are fairly abundant; apatite and ilmenite are accessory. The idiomorphic crystal was composed almost entirely of a cloudy mass of saussurite (zoisite and sericite). Stillwell has recorded similar occurrences (Stillwell 1911-14, pp. 48-55). He regarded the idiomorphic crystals as xenoliths in the dyke, calling them the composite type of meta-xenolith. They are best explained as metamorphosed cognate xenoliths derived from the decomposition of felspar. The marked angularity of some of the xenoliths, he says, shows that they have not travelled far along the dyke channel. They must have come from the magma chamber and therefore the present surface must be very close to the original magma reservoir. The very perfect shape of these idiomorphic crystals offers the additional possibility that they may be original phenocrysts which have been later metamorphosed along with the enclosing rock.

Somewhat different rocks but possibly of similar origin were noted about a quarter of a mile north of the mouth of Malkup Brook (17578, section 40594). A similar rock occurs near Toodyay but has not been described. The Malkup type, which had no definite outcrop, has a very mottled appearance due to irregular elongated light greenish white patches scattered through a dark fine grained slightly schistose hornblendic matrix.

In thin section the equidimensional hornblende crystals of this ground mass are hypidioblastic and show a pleochroism α = yellow green, γ = blue green. The extinction is $\gamma \wedge c = 14°$. Other constituents include completely saussuritised felspar, a little xenoblastic quartz and small grains of ilmenite. Sphene rims often surround the ilmenite.

The "phenocrysts" are most irregular in form and size, the largest being 1 cm. x 2 cm. In thin section they are seen to be completely replaced by a granular aggregate of epidote and zoisite with a little quartz. There is now nothing to suggest whether they are original phenocrysts in a dolerite dyke which has been metamorphosed or whether they are xenoliths of felspar which have been saussuritised by a basic magma. The authors are inclined to take the view that all the xenoliths in the quartz dolerites described in this section are metamorphosed cognate xenoliths.

(e) *Associated Granophyres.*—In hand specimen the granophyres are dark grey, massive, slightly porphyritic rocks. The phenocrysts are rather equidimensional crystals of quartz and felspar embedded in a fine grained matrix of quartz, felspar and biotite.

In thin section the porphyritic structure visible in the hand specimen is confirmed. The quartz phenocrysts occur in clear anhedral to subhedral somewhat fractured crystals which contain inclusions of the ground mass. The felspar phenocrysts, of which orthoclase is more common than plagioclase, are kaolinised and saussuritised. The borders of quartz crystals often possess rims of hornblende and biotite, particularly biotite which forms ragged chloritised crystals. Epidote occurs in yellowish green slightly pleochroic aggregates.

Practically the whole base of the rock is composed of a micropegmatitic intergrowth of quartz and orthoclase. This intergrowth forms a framework around the phenocrysts. In section (40628) there is a slight development of microspherulitic structure.

C.—Later Rocks.

1. Cataclasite.

The field appearance of the shear zone which runs along the western margin of Malkup Area is extremely varied. The edges are composed of granite which has been extensively injected by vein quartz. The centre is composed of quartz and limonitic material.

A section was made of a hard massive type from the centre in which the quartz was in the form of elongated lenses separated by thin bands of limonitic material. A type of palimpset structure was revealed in which larger quartz relicts were surrounded by a mass of granulated quartz. These more or less parallel oriented elongated relicts are extremely crushed and granulated. The surrounding quartz forms a microcrystalline mosaic of allotriomorphic grains. Iron ore occurs in bands throughout the rock, parallel to the elongation of the quartz relicts. The rock may be described as a cataclasite.

2. The Duricrust.

The extent of the duricrust, which is generally referred to in Western Australia as laterite, has already been mentioned. It has been observed lying above (and so is formed from) practically all the rock types found in the Area. In the south-east part of the Area where the duricrust covers the mica schists and quartzites two or possibly three types occur. On one little knoll bounded by breakaways, the laterite has obviously been derived from quartzite. Numerous nodules of quartzite, usually rounded and about three inches to four inches across, are studded through a very quartose ferruginous matrix. A similar occurrence has been noted in the north-west part of the Area but, in this locality, the bedding of the quartzite can still often be seen.

Just east of the small knoll mentioned above, a mica schist has been extensively laterised but it still to some extent preserves its schistose structure. It is purplish in colour and contains white streaks with a silky lustre, which may have been sillimanite. A little farther west, in the granite about two or three chains from the contact of the granite with the mica schists and quartzites, a banded laterite has been recorded. It has bands, rather constant in width (between 1/16 inch and 1/8 inch) which anastomose leaving long

narrow cavities. The bands are redder in colour than the ordinary laterite (resembling ochre) and they are extremely fine grained. The cavities however show the yellow colour of limonite.

The laterite formed over the granite and gneisses north of the Avon, is the pisolitic variety typical of the Darling Ranges (Simpson, 1912 and Clarke, 1919). Specimens were obtained from the centre of the area for future estimation of the iron and aluminium content. In the north-west part of the Area where the laterite has formed above the aplite and banded gneiss complex, a rather pretty "rose-bud" variety is found. Being essentially of the pisolitic type it shows well formed concretions around a kernel of quartz grains.

3. Talus Slopes.

Quartzites in particular have often formed steep talus slopes which frequently tend to cover up the mica schist bands. In several regions east of Munnapin Brook the quartzite talus slopes have formed banks up to 20 feet high even though the quartzite outcrop is quite some distance away. None of the slopes have been consolidated and hence they are extremely difficult to climb. The talus slopes of the sheer zone are very similar to these quartzite talus slopes.

4. Alluvium.

Mention has already been made of the presence of alluvium along the flood plain of the Avon River and at various places along its tributaries. The deposits of alluvium, at the mouths of the tributaries of the Avon are due to flooding during winter when the Avon dams back the waters of its tributaries. The greatest quantity of alluvium has been deposited by Munnapin Brook, which now meanders through a flood plain.

V.—THE TYPE OF METAMORPHISM AND ORIGIN OF THE ROCKS.

In the absence of chemical analyses of the rocks of the Malkup Area, field evidence and mineralogical characteristics are the only available criteria of the nature of the original rocks.

A.—Meta-Sediments.

1.—Quartzites.

Field evidence shows (a) a bedded appearance and (b) a highly siliceous composition.

Microscopical evidence shows (a) a general absence of cataclastic structure indicating recrystallisation and (b) the presence of oriented mica rods.

The field evidence clearly indicates a sedimentary origin for these rocks. They were deposited as sandstones, mostly very pure but in places containing slight impurities. Under the influence of pressure, acting vertically downwards on the beds, so that the mica flakes crystallised normal to the impressed force, the sediments were converted into the bedded quartzites now found. The presence of such minerals as epidote and diopside indicates than impurities of a calcareous nature were occasionally present. The metamorphism must have taken place in a region where recrystallisation was the dominant force.

2.—Mica Schists.

Field evidence shows that the mica schists are conformable with the quartzites which are regarded as of sedimentary origin.

The mineralogical composition of these schists which carry sillimanite, staurolite (?), garnet, andalusite, muscovite, biotite, chlorite and sericite, is consistent with that of a metamorphosed pelitic sediment (Tilley, 1926). Richness in alumina is the salient chemical characteristic of these rocks, the progressive metamorphism of which produces, at a certain zone, those aluminous silicates so highly characteristic of meta-sediments (Harker, 1932).

The metamorphism, judging by the minerals produced, must have been predominantly of a thermal character.

In the south-east part of the Area the mica schists sometimes become raher sandy and may even pass, without break, into quartzites.

3.—Jasper Bars.

The apparent bedded appearance and well marked banding in these rocks is indicative of an origin from sedimentary bedded iron ores. Owing to the absence of chemical analyses, there is very little evidence as to the exact nature of the original sediment. According to the minerals present, it appears to have been a rock composed of bands of limonite, chert and (Fe, Mg) carbonates.

The first stage of metamorphism would be the loss of CO_2 from the carbonates, the metallic ions still being retained. With increasing metamorphism these have reacted with silica to form cummingtonite. At the same time the reaction limonite $\longrightarrow$ haematite $\longrightarrow$ magnetite has been steadily proceeding. The production of magnetite would mark the attainment of a high grade of metamorphism. This is borne out by the production of cummingtonite. As a result of retrogressive metamorphism the magnetite is now partly replaced by an iron sesquioxide.

The production of blue-green amphibole requires a certain amount of argillaceous material to be present in the original sediment.

The position of this rock in the field (bordering on the intrusive granite on one side and on the mica schist on the other) and the complete lack of orientation of the amphibole, both indicate its formation under thermal metamorphic conditions.

B.—Meta Igneous.

1.—Basic Schists.

The main points to be considered in connection with the origin of the hornblende schists are:

(a) bedded arrangements in the field;

(b) presence of schistose structure, and absence of cataclastic effects in thin sections;

(c) the refractive index of the hornblende ($\gamma > 1.66 > \alpha$) is indicative of hornblende from epidiorites in the sillimanite zone (Wiseman, 1934, p. 394);

(d) the occurrence of diopside lenses and bands in the otherwise extremely uniform rock type. Harker (1932, p. 284) records the occurrence of colourless diopside in the more highly metamorphosed epidiorites at Belteraig near Banchory.

They appear therefore to be original sills or flows of basaltic composition which have been folded with the metasedimentary series during the period of orogenesis.

Prider (1938, p. 45) notes that in the Toodyay area the hornblende schists in their chemical composition are normal igneous rocks, such as would result from the crystallisation of a quartz dolerite magma.

2.—Granite Gneisses.

(a) Biotite—Microcline -Granite—Gneiss.

Augen gneiss. Field evidence shows that (1) it is apparently interbedded with quartzites of supposed sedimentary origin and (2) it has a uniform texture and composition along the strike.

Microscopical evidence shows (1) protoclastic structures rather than cataclastic (2) a composition not essentially different from a microcline granite (see micrometric analyses, Table II., column 3) and (3) the frequent occurrence of myrmekite.

The evidence permits of three interpretations (a) a gneiss of sedimentary origin (b) a granite sill (c) contemporaneous acid flows.

The protoclastic structure of the microcline augen has already been mentioned. Quartz crystals show orientation parallel to the gneissosity, without peripheral granulation and with slight development only of undulose extinction. There are two possibilities (a) the quartz has recrystallised from original crushed grains under tectonic activity (b) it has crystallised after the formation of the augen structure.

Prider (1938, p. 49) has made a fabric analysis of the quartz in a fine, even grained granite gneiss (from Toodyay) showing this marked elongation of unstrained quartz grains. After measurement of 200 grains he found no apparent concentration of the optic axes in any direction. A well marked fabric was obtained by him for several of the quartzites overlying the augen gneiss. He considered that the complete absence of any girdle in the diagram for the gneiss indicated that the quartz was of post tectonic crystallisation. Since the augen gneiss of Malkup Area is continuous with the Toodyay granite gneiss, it would appear that the former is a biotite-microcline-granite gneiss formed from a porphyritic microcline granite magma. When the microcline crystals had separated out the magma was injected as a sill into the quartzite. The beds beneath this sill, however, have not been observed. The microcline crystals were granulated with the production of protoclastic structures, and the quartz crystals crystallised after the main tectonic movements had ceased. The banded biotite-microcline-granite gneiss represents a more complete granulation of the microcline augen in the augen gneiss.

Fluxion gneiss. This gneiss is essentially of the same mineral composition as the augen gneiss. It differs in being finer grained, in showing complete absence of augen of microcline with peripheral granulation, and in having a faint linear parallelism due to the orientation of biotite flakes. In the field, it takes the form of a bathylithic intrusion, being essentially massive and unstratified. Its period of intrusion would apparently have been after the emplacement of the augen gneiss, but before the crystallisation of the quartz in the augen gneiss. During this period tectonic forces were still in operation with the resultant production of the gneissic structure.

(*b*) *Biotite-Oligoclass Granite Gneiss.* At present the exact relationship of this granite gneiss to (a) is not known. Where it occurs as patches in the biotite-microcline-granite gneiss it appears (Prider 1938 p. 61) that it could be the result of crystallisation of the residuum squeezed off from the earlier formed microcline. However this relationship does not hold where a similar rock type is contained as xenoliths in the more normal microcline granite.

3.—The Origin of the Xenoliths and Hybrids in the Fluxion Gneiss.

The progressive stages of incorporation of basic material by the gneissic granite magma have been treated elsewhere. The character of this basic material is seen to be almost identical with the basic schist (plagioclase amphibolite) which is believed to be a sillimanite zone epidiorite, with an original composition of a quartz dolerite. The reactions in this progressive assimilation have been summarised by Brammall (1936. p. 622) (augite) $\longrightarrow$ hornblende $\longrightarrow$ biotite $\longrightarrow$ chlorite. This alteration evolves epidote and a coloured variety of sphene. He notes that the Ca.-atoms trapped in the sphene and the (Al, Fe''')-atoms required for the transformation augite $\longrightarrow$ biotite could both be products of some change affecting the lime rich felspars.

During this progressive assimilation of the basic igneous rock and reciprocal hybridisation of the granite gneiss, differential movement has been proceeding with the production of a gneissic banding. This can still be included under the category of primary fluxion structure (Harker, 1932, p. 301), *i.e.*, the hornblende gneisses are actually hornblende granite gneisses.

The production of the hybrid rock type in the eastern section of the area appears to be due to some similar process. Here the absence of gneissic structures indicates lessened tectonic activity with the production of more normal rock types. The assimilation of these solidified basic igneous rocks by the granite magma may be likened to the processes of contrasted differentiation as expressed by Nockolds (1934, p. 37) where intermediate rock types may be produced by the reaction of solid basic igneous rock with an acid aplogranite magma. As to whether these basic igneous rocks have solidified from the same magma that later produced the acid residuum by a process of contrasted differentiation, there is no definite evidence, but the hybridisation effects are similar to those which would be expected under such conditions.

Pyroxene amphibole gneiss, which is found as xenoliths in both the fluxion and augen gneiss, appears to represent bands of metamorphosed impure argillaceous limestones.

The biotite granulite xenoliths in the biotite—oligoclase—granite gneiss seem to represent psammitic types of sediments.

C. *Doubtful Origin.*

Garnet amphibolite.—Field evidence shows that it is conformable with the mica schists. Microscopical evidence shows that in composition the minerals are probably Fe, Mg, Al, silicates. The evidence indicates that the garnet amphibolite was either a sill or a sediment conformable with the mica schists and quartzites.

As a sill it would have been injected at depth into heated sediments, for these show no contact metamorphic effects. To be in keeping with the present composition of the rock such a sill would have had the composition of a pyroxenite. Under metamorphism with relatively high shearing stress amphibolitisation would have altered the pyroxene completely to cummingtonite. The effect of succeeding load metamorphism would be to replace the amphibole by a garnet which has partly taken on the form of the radiating amphibole aggregates. The composition of the garnet corresponding to that of the amphibole is between pyrope and almandine.

It is possible that the garnet amphibolite is a meta-sediment derived from a siliceous ankerite rock rather poor in lime. Under the influence of shearing stress the silica and ankerite would react to form the amphibole.

$$(MgFe)\ CO_3 + SiO_2 \longrightarrow (MgFe)\ SiO_3 + CO_2$$

With a change of metamorphism to dynamothermal this amphibole with the addition of alumina would be replaced by garnet. Silica present represents that left over from the original reaction.

Thus this very interesting rock which consists of a pyropealmandine garnet, cummingtonite and quartz, may be the result of the metamorphism of an igneous rock, or that of a sediment.

VI.—GEOLOGICAL HISTORY OF THE AREA.

Descriptions have been given of a series of metamorphosed sediments and basic igneous rocks which have been intruded by later granite gneisses, granite and basic intrusives.

The bulk of the metamorphosed sediments consisted originally of interbedded sandstones and mudstones laid down in an early Pre-Cambrian sea. Occasionally beds rich in iron carbonates were deposited. The frequent occurrence of lime bearing minerals in the quartzites indicates the presence of limy intercalations in the original sandstones. Sills and flows of basic igneous rocks of tholeiitic and ultra basic composition were associated with these sediments. The grading of quartzites into mica schists indicates that whereas the sedimentation conditions were constantly changing, these changes were gradational.

After the close of the early Pre-Cambrian sea the accumulated sediments and igneous rocks were deeply buried and folded. As a result of this folding the series was thrown into an anticlinal structure. Minor schistose structures were produced in the basic igneous rocks and the quartzites were granulated.

This orogenic period was closed by a long-continued intrusion of a granite magma. It is believed that all the acid igneous rocks and granite gneiss in the Area are a part of this intrusion, but that with declining stress the later intrusions developed correspondingly fewer structures. Most of the metamorphism of the Area (which is predominantly of a thermal nature) is a result of this invasion of magmatic material into the sedimentary series.

This granite magma, the earlier intrusions of which crystallised as porphyritic microcline granite, was first intruded under strong stresses with consequent granulation of the phenocrysts and production of an augen structure. Before consolidation was completed a non-porphyritic microcline granite was emplaced farther to the north. In the short interval between the two intrusions there was a decline in the tectonic forces. The intrusive granite picked up fragments of older basic igneous rocks with

the production of hybrid rock types. These basic rocks were already solidified before the acid residuum was emplaced, and were possibly evolved in the same magma reservoir as the granite magma by some process of contrasted differentiation, or more likely belong to the sills and flows of basic igneous rocks associated with the meta-sedimentary series. The main Darling Range granite bathylith, together with its end stage products (aplites, pegmatites, quartz veins and felspar porphyries) followed farther to the west and south-west. Being intruded at a time when earth movements had practically ceased, cataclastic and flow structures are entirely absent.

The final phase of igneous activity is represented by the basic dykes, which intrude the granite and metamorphics along tension joints parallel to the direction of principal stress. It is suggested that the basic dykes originated from a magma reservoir which was very close to the present land surface in the western part of the Area. In certain places increased stress towards the end of crystallisation has resulted in the volatiles and gases playing an important part in late stage magmatic processes leading to the development of amphibole-porphyroblastic texture.

Later tectonic movements are represented by the production of a brecciated shear zone. Its age is unknown, but it was later than the basic intrusives and prior to the formation of the duricrust.

The area was then subjected to long continued erosion, and there is no evidence of any deposition of sedimentary series since Pre-Cambrian times.

Woolnough (1918, p. 385) considers that the superficial capping of ubiquitous laterite or duricrust belongs to a recent period when a great part of Western Australia had been reduced to a peneplain. Uplift of the peneplain followed and since that time the area has been dissected by streams as outlined in the physiographic section of this paper.

VII. ACKNOWLEDGMENTS.

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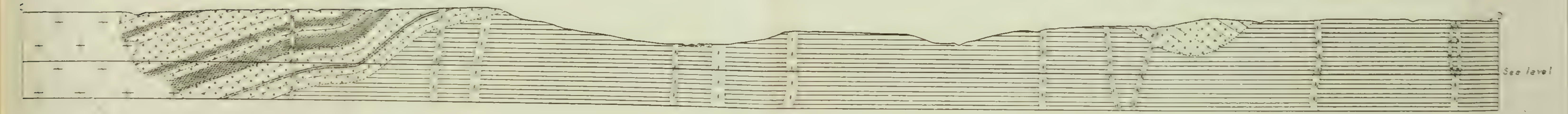
GEOLOGICAL MAP
OF THE
MALKUP AREA
AVON RIVER
Malkup Brook
Mortlup Brook
Cultivated Land
Cultivated
No Outcrop
Geology Obscured
Stream A
Stream B
Stream C
Stream D
Chitty
Market
REFERENCE
Geological Boundaries
Form Lines
Houses
Trig Stations
Location Lines
Strike and Dip
Section Lines
Scale 1in = 10 chains
LEGEND
Alluvium
Laterite
Shear Zone
Basic Intrusives
Porphyry
Pegmatite
Granite
Garnet Amphibolite
Microcline Granite Gneiss
Oligoclase Granite Gneiss
Hornblende Gneiss
Hybrid
Basic Schist
Eulysite Type
Quartzite
Mica Schist
LOCALITY PLAN
20 Miles
PERTH
W.F. Cole.
C.S. Gloe.

Section A–B



Section C–D

— Geological Sections —
of
— Malkup Area —

0 1000 2000
Natural Scale of Feet
Legend as in Geological Map

14.—LOAD CARRIED BY FLOOD WATERS IN THE SOUTH-WEST.

By DOROTHY CARROLL and E. de C. CLARKE.

Read 11th June, 1940; Published 4th November, 1940.

INTRODUCTION.

The only published information about the quantity of material removed by rivers in south-western Australia appears to be an article by Teakle (6) on soil erosion in the northern agricultural areas and one by Finucane and Forman (2) on the load carried by the Swan River during the 1926 flood.

We record here some rough and ready measurements which have been made by students and staff of the Geological Department of the University of Western Australia since 1926 in the North Irwin and Swan Rivers, in the Chittering Brook, and in the Collie and Preston River systems which discharge into Leschenault Inlet. Much help has been received at various stages in the securing of these results from Messrs. S. E. Terrill, R. S. Matheson, P. Dunlop, E. S. Clarke, and S. J. Mayne, to all of whom we wish to record our thanks while absolving them from any responsibility for the form or content of this paper.

All the streams discussed are of the intermittent type; most of them flow only for a short time in the rainy season (winter) but those of the Collie-Preston system may continue running until early summer. In this paper the words "flow," "drain," etc., are, for the sake of brevity, used as if the streams were perennial.

The measurements were made in 1934, 1937, and 1939 during floods which followed exceptionally heavy rains. Widespread floods occurred in 1934 and 1939, but 1937 was a normal winter with a few heavy falls of rain.

The figures obtained indicate that, because of the infrequent opportunities which the rivers have of carrying a large load, the average rate of erosion in the south-western part of Australia is very much less than the world's average. This would, of course, have been expected in view of the topography, geology, and climate of the region. It seems worth while, however, to record the figures, while emphasising that they are only rough approximations to the true carrying capacity.

METHODS OF OBTAINING DATA.

In each case a part of the stream was selected which was most nearly straight and in which the channel was of approximately uniform cross section. In the Irwin and Chittering gaugings, cross sections at the two ends of the reach were obtained by measurements at 2-foot intervals; the area of the cross section in the *Table* is the mean of the two. In the other gaugings it was only possible to measure one cross section.

"Surface velocity" was calculated by averaging the rate of travel, over the comparatively straight reach, of a number of floats released at different distances from the banks. The figures so obtained and given in the *Table* are necessarily only the approximate rates of flow. One authority (4) suggests that 84% of the surface velocity is a fair average for the rate of movement of the whole body of water, but others consider that 75% only should be taken and we have used this latter figure in arriving at the column "mean velocity," from which the "load" has been calculated.

The figures in the column "Load, gm. per litre" were obtained by evaporating to dryness a measured quantity (usually 2 to 3 litres) of the water, and weighing the residue; they therefore represent suspended plus dissolved matter. Samples in the North Irwin and Chittering were collected at various positions in the cross section both near the surface and near the bottom, since the amount of load will obviously differ in different parts of the cross section, but from the other streams it was only possible to collect samples from the middle near the surface. In these cases therefore the calculated load errs on the light side. A more serious under estimate moreover occurs in all the results, because no attempt could be made to calculate the quantity of material rolled along the stream bed, which in the more rapid streams was undoubtedly an important fraction of the load.

SUMMARY OF DATA.

The figures obtained as described and the calculations therefrom may be tabulated as follows:—

River Gauged.	Date.	Observed Results.			Mean* Velocity.	Discharge.	Load.	
		Cross Section.	Surface Velocity.	Load.				
		sq. ft.	ft. per sec.	gm. per litre.	ft. per sec.	cub. ft. per sec.	gm. per cu. ft.	Tons per day.
(1)†North Irwin	16–4–34	60	2·8	2·13	2·10	126	60·3	645
(2) Chittering Brook ...	20–5–37	12	3	0·0055	2·25	270	0·16	3·7
(3) Swan ...	11–3–34	...	...	0·0236	...	...	0·67	...
(4) Collie ...	13–8–39	2,518	1·5	0·225	1·13	2,840	6·36	1,530
(4A) Collie ...	30–8–39	2,683	1·33	0·21	1·00	2,683	5·94	1,360
(5) Brunswick...	30–8–39	666	2·85	0·13	2·14	1,430	3·68	450
(6) Preston ...	15–8–39	725	3	0·247	2·25	1,630	7·00	970
(7) Preston ...	28–8–39	600	1·33	0·207	1·00	600	5·86	300
(8) Preston ...	28–8–39	1,044	5	0·29	3·75	3,920	8·21	2,740
(9) Preston ...	28–8–39	840	5·6	0·214	4·20	3,530	11·9	3,570
(10) Ferguson...	15–8–39	70	5	0·22	3·75	263	10·6	238
(11) Leschenault Estuary at Pig Island near mouth	28–8–39	2,110‡	1·6	0·23	1·20	2,530	3·4	728

* Mean velocity is taken as 75 per cent. of observed surface velocity. † Numbers refer to position on map. ‡ Cross section given by the Public Works Department for low water mark; as the Estuary was in flood at the time of observation the cross section must have been greater than that given here, but there was no means of measuring it.

NOTES ON CONDITIONS IN INDIVIDUAL STREAMS.

1. *North Irwin.*—This stream rises about 20 miles above the place where it was gauged (for positions of streams and gauging places, see *Map*). From its source it flows over the Pre-Cambrian complex for 18 miles, and for the remaining two miles it flows through Permian shales and sandstones. A large part of this Permian country has been cleared of scrub and in late summer is almost devoid of vegetation; consequently heavy "autumn" rains like those of April, 1934, remove a very large quantity of soil and soft rocks.

Very heavy rain fell in the district during the first fourteen days of April, the official records being 5.20 inches at Nangetty and 5.63 inches at Mingenew. The usual April rainfall is 0.80 inches. This fall was therefore very exceptional for the time of the year, and those who saw the flood formed some conception of the large amount of "work" done by a stream which drains an area of approximately 150 square miles. It had been unfordable for several days before 16th April, when the samples were collected and was rapidly falling at the time of the gauging, consequently the calculated load is, apart from the inadequacy of the method, certainly an under-estimate.

Chittering Brook.—The Chittering is about 30 miles long and drains an area of about 335 square miles which is practically all in the Pre-Cambrian complex of schists, quartzites, and greenstones. Only the lower slopes of the valley are cleared, and as the cleared parts are under permanent grass, soil erosion is slight. The figures obtained for this stream are the nearest approach to the true rate of erosion in the western part of the "Great Plateau of Western Australia." All other streams gauged have part of their courses in more easily eroded rocks—hence the bigger "loads."

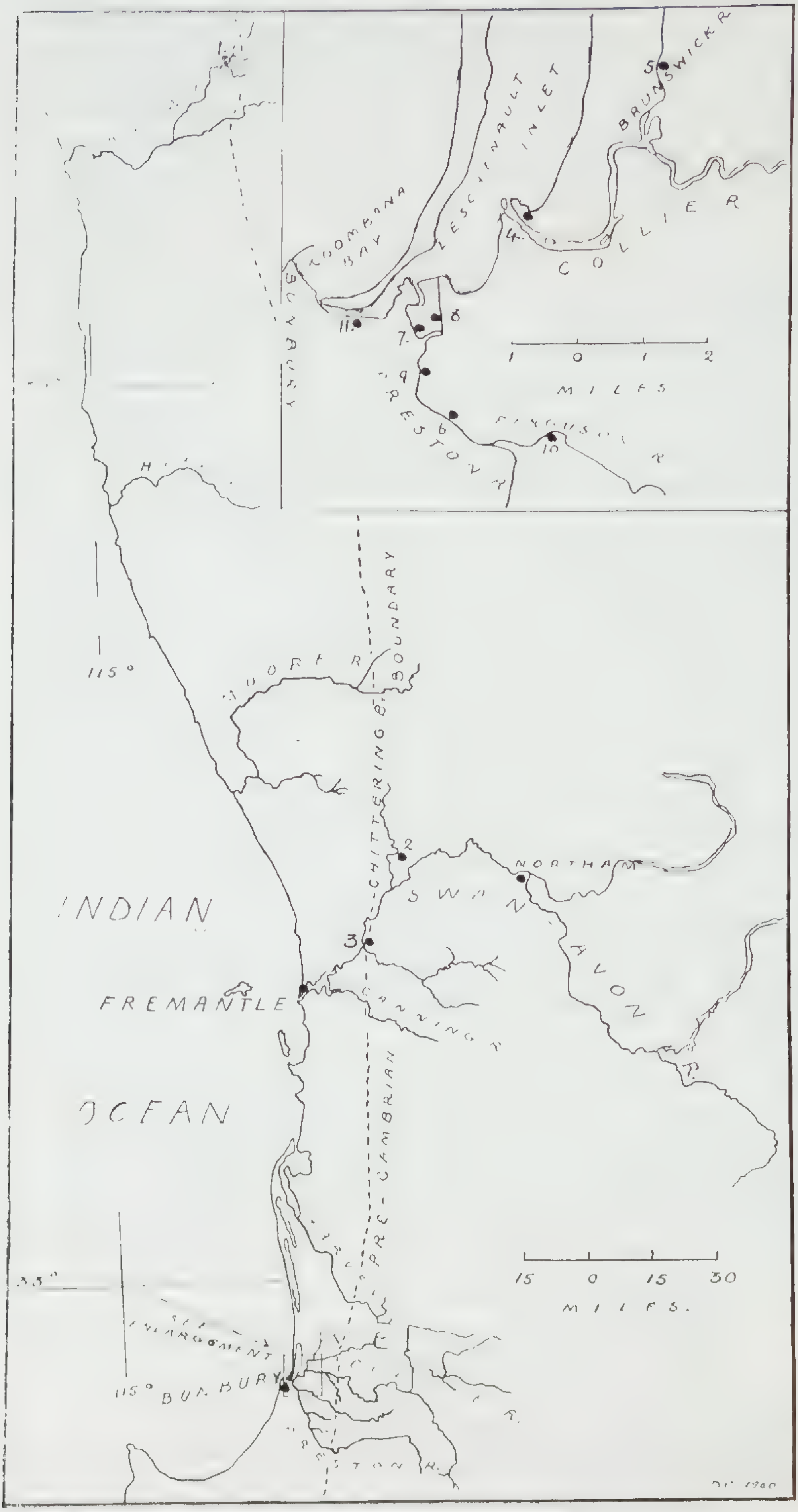
In May, 1937, the Chittering Brook was in flood following heavy rains. There are no daily rainfall records kept in the Chittering Valley but the month's rain for May in that year was 6.58 inches at Chittering Park, and 6.68 inches at Innaminka. Apparently most of this rain fell before 17th May, for the stream began to flood on 17th and was subsiding on 20th May, when the gauging was done. The rain was evidently patchy for at Toodyay the rainfall up to 17th May was 0.72 inches, but 2.29 inches fell on 18th, bringing the total to 3.91 inches, whereas the average fall for May is 2.87 inches.

A sample of the water from the Chittering Brook was analysed in the University Chemistry Department through the courtesy of Dr. G. A. Elliot, with the following result (an analysis of Mundaring water (5) is added for comparison):—

	Chittering Brook.	Mundaring.
	ppm.	ppm.
Temporary Hardness	102 (as $CaCO_3$) ..	...
Permanent Hardness	29·2	...
Chlorides	227	210
SO_4	50	27
Ca	13·5 and 11	10
Mg	18·3	18
Fe	8	tr.
SiO_2	n.d.	9

3. *Swan.*—A single sample of water from the Swan River at Barker's Bridge, Guildford, was collected on 11th March, 1934, by Mr. S. J. Mayne, but no figures for the velocity or cross section of the river are available. The amount of material carried was 0.0236 gramme per litre, considerably more than during the 1926 flood. On the days preceding 11th March, 1934, there were particularly heavy falls of rain. Some official records are as follows:—

	March, 1934.	Average March Rainfall.
	inches.	inches.
Northam	5·68	0·72
Toodyay	9·22	0·68
Guildford	5·19	0·61
Mundaring	4·93	0·96
"Belvoir," Upper Swan	3·85	n.r.



Map of part of the South-West of Western Australia, showing places where rivers were gauged and sampled, and Pre-Cambrian boundary. (Compiled from Western Australian Lands and Surveys map of part of the South Western Division of Western Australia, 15 miles to the inch; and Lands Department Litho. 411 80.)

This flood carried a heavier load than that of 1926, probably because it occurred in March before the ground had been soaked by more gentle rains, and therefore material was more easily removed than by a later winter flood.

The Swan-Avon River is shown on the Lands Department maps as rising near Wickepin, and therefore flowing for 125 miles over the Pre-Cambrian complex. Before reaching Barker's Bridge it has travelled for about 15 miles over the unconsolidated veneer of the Swan Coastal Plain. Actually water has been known to flow from near Menzies westwards to Northam where the Mortlock joins the Avon. The drainage area of the Swan-Avon is about 13,000 square miles, exclusive of the abovementioned occasional extension to the goldfields.

4. *Rivers entering the Leschenault Inlet, Bunbury.*—The Collie and Preston river systems, draining an area of approximately 1,400 square miles on the Darling plateau and coastal plains, discharge into the Leschenault Inlet at Bunbury (see map).

Leschenault Inlet is a wide shallow stretch of water which extends from its narrow outlet into Koombana Bay for about 10 miles to the north and parallel to the coast from which it is separated by a strip of sand dunes one-quarter to one-half mile in width. Although floods do not occur every year a great deal of material has been deposited just at the mouth of the river and in the wide shallow stretches of the inlet near by, for in the mouth a fairly large island has been built and in summer there is hardly sufficient water for even a small boat. The artificial channel, made many years ago, has also silted up and is practically useless for navigation purposes; nevertheless, the Collie river itself is very deep in places within a mile or two of its mouth.

The Collie river enters the coastal plain through a steep-sided, well-established valley south-east of Roelands. The river has built rich alluvial flats at Roelands and Burekup where terraces seem to indicate that there have been at least two small uplifts, of the order of 20 feet each. The river has cut deeply into its own alluvium, and is now depositing another series of flood plains. The Wellington dam, conserving water for irrigation purposes, is built in the valley some miles behind the scarp, and now reduces the amount of water reaching the plain. For part of its course the Collie flows over the Permian rocks of the Collie coalfield but the greater part lies in the Pre-Cambrian complex.

The Brunswick, a tributary of the Collie, drains the country north of the Collie, which it joins near its mouth. It has alluvial flats like those of the Collie, but smaller. Both of these rivers cross Pre-Cambrian country, which, away from the scarp, is covered by heavy laterite. Easily erodable soils have only developed on the valley sides and on the western side of the scarp.

The Preston river rises in the plateau country about 30 miles east of Donnybrook and flows in a wide valley, steep-sided on the north where the rocks are Pre-Cambrian, but of a more mature appearance on the southern side where there are remnants of the Donnybrook sandstone series. In the Pre-Cambrian rocks at Donnybrook, the valley is quite narrow and steep-sided. Immediately west of Donnybrook the river has deposited alluvium where it leaves the Pre-Cambrian; between Donnybrook and Boyanup it has eroded a mature valley in sandstones which are Permian or Triassic (3). In

the coastal plain the river has cut steep banks, and no flood-plains occur until after it is joined by the Ferguson at Picton. Near its outlet the Preston meanders and is at grade; it has always flooded badly in winter near its mouth, but this has lately been remedied by cutting a more direct channel to the estuary.

Normally the Collie and Preston rivers are rather sluggish; water usually ceases to flow in the summer but is fairly brisk in winter.

Observations on the load carried by these rivers were made in August, 1939, when the rivers had been in flood for about a fortnight after continual heavy rain in July. Official rainfall records in the district for July and August are as follows:—

	July, 1939.	July Average.	August, 1939.	August Average.
	inches.	inches.	inches.	inches.
Bunbury	8·85	6·74	6·59	5·19
Collie	11·60	7·49	12·54	5·76
Brunswick	12·19	7·83	11·14	6·33
Donnybrook	8·95	7·74	10·72	6·05
Boyup Brook ...	5·34	4·92	5·88	4·10
Ferguson	9·83	n.r.	10·65	n.r.
Dardanup	10·90	n.r.	8·49	n.r.

The number of wet days at these towns during July and to the middle of August, 1939, are: Bunbury, 31; Collie, 34; Donnybrook, 36; Boyup Brook, 30. These are all much above the usual number of wet days.

The discharge and amount of material carried by these two river systems per day are given in the *Table*. Taking three weeks as the period of maximum flooding and the figures in the *Table*, the following approximate figures for the total load during the flood period are:

	Tons in three weeks.
Collie river	30,000
Preston river	63,000
Leschenault Estuary, near outlet	16,000

The sampling in Leschenault Estuary needs some explanation; owing to bad weather conditions it was not possible to obtain samples at the outlet of the Estuary into Koombana Bay (see enlarged inset on *Map*) but samples were collected opposite Pig Island about half a mile from the outlet. The figure of 16,000 tons may therefore be slightly on the high side, for some deposition could occur between Pig Island and the outlet.

The Estuary received about 93,000 tons of material from the Collie and Preston rivers; 16,000 tons passed into Koombana Bay and eventually out to sea, leaving 77,000 tons to be deposited in Leschenault Inlet. It is interesting to note that the Swan-Avon river system discharged 863,000 tons of material during the 1926 flood (2).

The figures for the load carried by the Preston river show that it varied considerably. The Preston at the main road bridge (No. 6; for these positions see inset *Map*) carried 970 tons per day; at Glen Iris (No. 9) the load had increased to 3,570 tons, but only 300 tons per day passed through the original channel at Leschenault (No. 7) which used to flood badly every winter before the new channel was cut. The load was 2,740 tons per day in the new channel (No. 8), indicating that about 500 tons per day was being deposited in the new channel.

CONCLUSIONS.

The tabulated results give a number of figures which are of interest because they give some quantitative idea of the work being done by the streams observed. The quantity of material carried by the North Irwin, in grammes per litre, is many times greater than that carried by any other stream so far examined in the South-West. This may be due partly to the bareness of the country at the time of the exceptional rains, partly to the fact that during the summer the stream bed is dry except for a pool or two; therefore there is abundant fine material mixed with sand, pebbles, and angular flat pieces of rock which must also have been rolled along the bed but did not enter into the samples of water collected. The rate of flow is about the average rate of flow of the other streams. Much of the material may not have been transported very far. The amount of material carried by the North Irwin may be of an order characteristic of the rivers in the North-West, for which we have no information at present.

The Collie and Preston rivers carry a greater load, when in flood, than does the Swan; such a stream as the Chittering, which is almost wholly in the Pre-Cambrian rocks, carries a very small load.

It is evident that a great part of the load of these rivers seems to be picked up from the more easily eroded soils and sands of the coastal plain, and does not come directly from the higher Pre-Cambrian country. The actual fall of any of these rivers is not great; that for the Swan-Avon and for the Collie and Preston rivers cannot be more than 1,000 feet.

The amount removed by the Collie and Preston systems during the flood period per square mile of drainage area is 67 tons. The world's average per year per square mile is 62.3 tons (1).

The results show that the rate of erosion in this part of south-western Australia approaches the world average for years of unusually heavy rainfall, but as these only occur once in every six to eight years, the true rate of erosion is many times less than in countries with a better rainfall and greater heights which give the rivers more eroding power.

Unfortunately there are no records of the usual winter loads of these streams for comparison with the figures given here, which, as explained above, must be regarded as very approximate, and as under-estimates. Observations (without measurements) seem to indicate that it is only in times of abnormal flood that much material is removed.

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THE CERAMIC RESOURCES OF SOUTH-WESTERN AUSTRALIA.

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By H. Bowley, F.A.C.I.

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INTRODUCTION.

The discovery in 1911 that the vitrified drain pipes required for the newly initiated drainage of Perth would have to be imported at high cost was responsible for the staff of the then Geological Survey Laboratory instituting a research into the ceramic resources of South Western Australia. Inquiries showed that this high cost was due to the fact that the pipes were either imported already made from the Eastern States or were made in Perth out of clays wholly, or almost wholly, imported from Victoria or Tasmania. This seemed quite unnecessary in view of the wide range of clays which had been observed in the State although manufacturers expressed the opinion that no Western Australian clay was suited for vitrified pipe making. The suggestion that if no single clay were suitable, a mixture of two or more clays might be found to serve was unfavourably received. This was a distinct challenge to experimental chemists, which could not be left unanswered, and experiments were immediately inaugurated to prove whether or not it was a fact that no mixture of local clays could be found to yield a satisfactory vitrified pipe.

The requirements for such a mixture were definite. The grain must be fine, the mixture highly plastic, it must give a dense vitrified body at about 1300°C., which would take a salt glaze, the total shrinkage must not be excessive, whilst the colour was unimportant. It was first assumed that a good base would be one of the Collie Coalfield sedimentary shales, many of which are very fine grained, semi-refactory, with low air and fire shrinkage, and of medium plasticity, whilst they are available in very large tonnages. To blend with this it was necessary to find an equally fine grained clay of higher plasticity and containing sufficient iron to flux the more refractory clay and bring its vitrifying temperature to the right point and enable it to take a salt glaze. Such clays were found at several points on the Swan Coastal plain, and experiments were made with one from Belmont obtained in close proximity to existing pipe works. After a number of experiments the following mixture was found to give an excellent body.

Mujar*—pale grey shale	60 per cent.
Belmont†—red alluvial clay	40 per cent.

This mixture was highly plastic and fine grained, giving, when trial pieces were burnt at 1300°C., a grey well vitrified, extremely dense and tough body, quite impervious to water, even without glazing, and taking a salt glaze well by virtue of its iron content. The air and fire shrinkages were moderate.

* Near Collie. † Near Perth.

This practical demonstration on a small scale appealed at once to local manufactures and financiers and had immediate results of great importance to the State, viz.:

(1) The permanent establishment of a new factory in Perth for the production of such ware;

(2) The exploitation in large quantities of a mineral previously unutilised;

(3) The material reduction in price of drain pipes, and, therefore of sewerage connections;

(4) It opened the eyes of local ceramic manufacturers for the first time to the practical value of scientific investigation, and the possibility of discovering a suitable mixture of clays for any particular work when no single clay could be found possessing the desired properties.

Later experiments indicated the feasibility of substituting for Belmont clay other coastal-plain clays of similar type, *e.g.,* that from Coolup; and for Mujar shale, similar shales from other parts of the Collie field. Finally freight costs were reduced and working properties improved by adding a third fine plastic clay from Mundijong, capable by itself of vitrifying at about 1300°C.; a suitable mixture being:—

Collie	40
Mundijong	30
Coolup	30

No imported clay has been used since that time in this industry.

From 1911 till 1917 clays continued to be tested in the Geological Survey Laboratory. In the latter year the then Minister for Industries (Mr. R. T. Robinson) was so satisfied with the importance of the work that he suggested a more thorough stocktaking of our ceramic resources and authorised the construction in the laboratory of a small kiln, a potter's wheel and other subidiary equipment for semi-commercial trials, and the engagement of a practical potter with wide experience to collaborate with the scientific staff in carrying out these trials. Notices were put in the daily and weekly press inviting samples of clay in not less than 10 lb. parcels to be submitted by the public for trial, details being required as to locality, thickness of overburden, probable extent, etc., of the deposit.

In 1918 these investigations were continued with funds supplied partly by the State, partly by the Federal Government through the then Commonwealth Bureau of Science and Industry. Kiln tests were continued up till the middle of 1919 when lack of funds prevented their continuation and the intensive campaign ended, giving place to a renewal of prior conditions with laboratory tests on a small scale on a limited number of new samples. This condition prevails at the present day.

The only use to which the kiln has been put since that date was in 1924 when test pieces were prepared in it for the British Empire Exhibition. For the ceramic exhibition there displayed, bronze medals were awarded in 1924 and 1925. Apart from brief notes in annual departmental reports and a summary of our knowledge of local ceramic materials prepared for publication in an official Mineral Resources Pamphlet, the results of the experiments have never been published. Individual reports, however, have been furnished to persons submitting samples, and all the data, including the test pieces, have been at all times available in the Government Chemical Department, to local manufacturers and other interested parties.

Particular attention was directed during the most active years of the research to the State's resources in white clays, felspars and other minerals required in the manufacture of white domestic ware which had not, up till then, been produced locally. Subsequent results have shown how successful this was. Abundant supplies were located of true China Clay having properties indistinguishable from the world renowned Cornish clays. Whilst ball clays with the high plasticity of English and United States clays were extremely rare, large deposits were disclosed of a less plastic variety of white clay, to which the term semi-ball clay was given, which could take the place of the usual mixture of ball clay and China Clay.

Of subsidiary minerals, high grade felspar was located in abundance as well as suitable substitutes for the European flint.

Another line of ware, terra cotta roofing tiles, received attention. The somewhat similar but rougher and more porous flower pots and agricultural drain pipes, had been made without intermission for many years, from alluvial clays in the Swan Valley. Except, however, for a few roofing tiles made in 1901 at Woodbridge, and a few more made in 1904 at Belmont and Bunbury, architects had been driven to use the most unsightly, although efficient material, corrugated iron, for the roofs of all but a few very expensive houses, on which Marseilles tiles were employed. War years brought a great increase in the price of galvanised iron and a shortage of supplies, with the result that a well-known importer of French tiles began to make enquiries in the State as to the possibility of manufacture locally. Full use was made of the information available in the Government Laboratory and in the middle of 1917 the first permanent factory for the manufacture of Marseilles-pattern tiles was established in Perth.

Other experiments, many of them leading to practical results in greater or less measure, had for the object the improvement in quality of local red brick and firebrick, the possibility of manufacturing assay crucibles and scorifiers, as well as sanitary ware, glazed tiles and hard porcelain. These results have been most gratifying. As direct or indirect outcomes of this research, the following may be recorded as particularly noteworthy:—

(1) The permanent establishment of a vitrified pipe factory;

(2) An increase and improvement in the manufacture of refractory bricks and blocks of various types;

(3) The establishment in 1921 of a white ware industry, centred mainly in the Calyx Porcelain Works at Subiaco, where at present a large range of table and other domestic ware of semi-porcelain is produced as well as some vitrified ware and sanitary ware. This was the direct result of a scientific ceramic stocktaking revealing the presence of suitable clays, felspars and flint substitutes in the South-Western part of the State. Profiting by the information available, a second factory shortly afterwards began to put cream coloured domestic ware on the market.

(4) The establishment of a permanent roofing tile industry revolutionised the appearance of the newer suburbs of Perth, where terra cotta tiles have almost completely taken the place of corrugated iron on all better class residences.

(5) The location of the first cement works in the State was assisted materially by the large amount of information available in regard to the chemical and mechanical composition of our alluvial clays.

Although there are now a large number of ceramic industries in the State, and many clay deposits are being worked to supply them, the research must not be looked upon as completed. Well sinking is constantly disclosing fresh deposits of good clays which require listing and recording, for it is now an established fact that rock weathering has extended to a great depth in south-western Australia, and underneath an uninviting lateritic or sandy surface there lie in many places great thicknesses of pure white and other valuable clays whose properties and capacities are well worth testing.

On the other hand, from manufacturers still come such questions as: (1) Where can we get a better substitute for English ball clay than we have at present? (2) cannot we get supplies of suitable felspar nearer to the factories than Coolgardie? (3) how can we overcome the small black specks which appear in our white ware from time to time? (4) what is the best mixture of local materials to make a good electrical porcelain? (5) how can we reduce the high porosity of our red bricks without unduly raising the cost, etc.?

A brief resume of the ceramic industry in Western Australia will not be out of place in this introduction

Red Brick.—This appears to have been the first clay industry started in Perth, house bricks of yellow to red colour being made from the clay beds lying between St. George's Terrace and the river. This was rather a sandy clay, and whilst some of the bricks have stood well, others have yielded badly to wind erosion. Later the centre of the industry moved to East Perth, then to the Midland Junction district, where a large number of kilns are still in operation. In all cases a rather sandy clay is being used, giving a brick of fair appearance but of high porosity. The oldest houses in Perth can still, in most cases, be recognised by their brickwork, consisting of alternate reddish brown headers, and yellow stretchers. The Town Hall was built of bricks made at what is now Queen's Gardens in East Perth.

In 1903 a great advance was made in brickmaking by the discovery that a pressed brick of excellent colour and finish could be made of a mixture of plastic alluvial clay and ground slate from the soft Precambrian beds of the Armadale district. This discovery was promptly followed by the installation of a Hoffman kiln, and other necessary plant for the production of such bricks. The production still continues and the success of the first plant has been followed by the opening of quarries and erection of similar plants at Byford and Cardup.

Red bricks have also been made at Kelmscott, Bunbury, Albany, Coolgardie, Kalgoorlie, and many other country towns from local alluvial or eluvial clays.

Refractory Brick.—Firebrick and fire-lumps appear to have been first made at Glen Forrest (then known as Smith's Mill) as far back as 1896. Work is still carried on there and a larger quantity of firebrick and miscellaneous mouldings is made from a mixture of completely kaolinised granite and similarly altered epidiorite. Such deposits are of widespread occurrence in the Darling Ranges. In 1900 a second works for the manufacture of refractories was established at Clackline. Here the raw materials used are kaolinised schistose greenstone, kaolinised dolerite and altered sillimanite schist, a kaolinised mica schist and a decomposed pegmatite, all of which

are obtained in the quarries adjacent to the works. In recent years a further plant was established in East Perth, the clays used being of various types from a number of localities in the Darling Ranges.

Many years ago some magnesite bricks were made at Ravensthorpe for use in the copper smelting plant there, but the industry, which was on a very small scale, long since died out.

No silica bricks have ever been made in the State, though such bricks are imported in some quantities, and there are indications that suitable quartzite is obtainable locally,

Domestic White Ware and Cream Coloured Ware.—As already stated none of this was made in the State till 1919, when the Calyx Company started the manufacture of plain white stone-ware, or semi-porcelain table ware. Later a second factory started making similar ware and cream coloured kitchen ware. These industries have advanced until now all kinds of plain and ornamental domestic ware for table, toilet, etc., are produced.

Vitrified Ware.—No fine hard porcelain has yet been made, but a little electrical porcelain has been put on the market. In rougher ware of light colour, acid carboys and ink bottles are made. The main line of vitrified ware made is drain pipes, with smaller amounts of sanitary fittings, telephone conduits and miscellaneous salt glazed ware with similar body.

Terra Cotta Ware.—Complete local supplies of flower pots and porous agricultural drainpipes have been made for many years from the finer and less sandy sedimentary clays of the lower Swan Valley. A few roofing tiles appear to have been made at Bunbury and Guildford fifty years or more ago, but the industry died out. Again in 1901 roofing tiles were made at Woodbridge, sufficient to cover Parliament House. From 1904 onwards shingle tiles have been made in varying quantities at Belmont near Perth, but it was not till 1917 that the manufacture of high-class roofing tiles was begun in earnest. This industry has now reached to important dimensions as explained on a previous page. Architectural terra cotta has been made on a small scale and a good example is to be seen on the face of the Sculpture Gallery in Perth.

CONSTITUENTS OF CLAYS.

No clay is composed of a single chemical compound. On the contrary, even the whitest and purest looking of them is such a heterogeneous mixture, that no two authorities are agreed as to a final definition of the term "clay." In the ultimate analysis, however, it will be found that all clays contain silica and alumina in excess of any other chemical unit and that combined water is an essential constituent. Within the limits expressed by this statement, wide variations are known in the ultimate chemical composition, and still wider variations in the proportions of the several mineral units built up of the simple oxides shown in a chemical analysis. A few of these minerals are present in comparatively large amounts in almost all clays; others are invariably only very minor constituents; others again are sometimes abundant, sometimes rare, or absent altogether. These variations give rise to differences of behaviour in manufacturing processes which are used to define the different types of commercial clays.

In order to understand the behaviour of the mixed clays it is necessary to consider the properties of the individual mineral units. The complete list of minerals believed to occur in clays is as follows:

Major Constituents

Kaolinite	$Al_2O_3.2SiO_2.2H_2O$
Halloysite	$Al_2O_3.2SiO_2.4H_2O$
Quartz	SiO_2
Limonite	$Fe_2O_3.H_2O$
Muscovite	$2H_2O.K_2O.3Al_2O_3.6SiO_2$

Minor Constituents

Salt	$NaCl$
Calcite	$CaCO_3$
Felspar	$K_2O.Al_2O_3.6SiO_2$
Chlorite	$(2H_2O.2MgO.Al_2O_3.SiO_2)$ + $(2H_2O.3MgO.2SiO_2)$
Opal	$3SiO_2.H_2O$
Gibbsite	$Al_2O_3.3H_2O$
Humus	C, H, O, N, in indefinite proportions
Coal substance	C, H, O, N, in indefinite proportions

Constituents rarely, if ever, present in quantities exceeding one per cent.

Pyrite	FeS_2
Rutile, Brookite, Octahedrite ...	TiO_2
Doelterite	$TiO_2.H_2O$
Ilmenite	$FeTiO_3$
Siderite	$FeCO_3$
Zircon	$ZrSiO_4$
Gypsum	$CaSO_4.2H_2O$
[illegible]	$6H_2O.K_2O.3Al_2O_3.$[illegible]

Doubtful Constituents

Montmorillonite	$8H_2O.MgO.Al_2O_3.5SiO_2$
Saponite	Hydrated silicate of aluminium and magnesium
Sepiolite	$2H_2O.2MgO.3SiO_2$
Talc	$H_2O.3MgO.4SiO_2$
Vanadium silicate	Composition doubtful

These constituents can be divided into two main groups as regards their physical properties, viz., crystalloids, of which the principal are kaolinite, quartz and mica; and hydrogels of which the principal are halloysite, limonite and humus. The former group form the rigid skeleton of a raw ceramic body, the latter, with water, the lubricant and adhesives which enable the wetted clay to be modelled and subsequently to retain its shape.

Major Constituents

Kaolinite. Hydrous silicate of aluminium, $Al_2O_3.2SiO_2.2H_2O$. This is a pure white crystalline substance, occurring in all clays in minute scales, most of which are less than one-tenth millimetre in diameter and may be of colloidal size. The scales are soft and pliable. On burning, kaolinite yields pure white bodies at all temperatures, but becoming denser and harder at higher ones. Complete fusion only occurs at 1,820°C., so that this mineral is the most refractory of all the important constituents of clays. It forms by far the greater part of most "washed kaolins" or "true china clays" and is plentiful in all commercial clays, the utilisation of which depends to a large extent upon the properties of kaolinite.

The chemical changes taking place during the heating of kaolinite are briefly*—

Up to 100°—Evaporation of adherent moisture.

450-650—Complete removal of combined water (endothermic reaction).

(650-750°) (Sato) (1000° (Mellor)—Dissociation into alumina and silica (strongly endothermic).

1200-1300°—Recombination of alumina with part of the silica to form fibrous crystals of mullite, $3Al_2O_3.2SiO_2$, the balance of the silica appearing as a crystobalite (SiO_2)†.

Kaolinite is very resistant to boiling strong hydrochloric acid, but is decomposed completely by hot fuming sulphuric acid.

Halloysite.—Hydrous silicate of aluminium, $Al_2O_3.2SiO_2.2H_2O + 2H_2O$. The proportion of water varies under different conditions.

Air dried	$Al_2O_3.2SiO_2.2H_2O + 2H_2O$ ...	4 Mols.
Dried over sulphuric acid	$Al_2O_3.2SiO_2.2H_2O + H_2O$ ...	3 Mols.
Steam dried	$Al_2O_3.2SiO_2.2H_2O$	2 Mols.

This is one of the commonest and most important constituents of clays. It is a pure white or very pale green mineral of the consistency of wax. It is a typical hydrogel, non-crystalline, and readily swelling and dispersing in water into a colloidal suspension. It is the chief, and often the sole, colloid in clays, being identical with Mellor's "clayite" (a term unknown to mineralogy). With certain proportions of water it forms a thin slime or cream of high lubricating properties. It is the presence of this slime between the crystalline particles of wetted clays that gives them their essential property of plasticity, and it is the drying of this slime in intimate contact with the other constituents which binds them together into a strong mass which can be handled without crumbling.

Halloysite, on heating, behaves in a very similar manner to kaolinite, except that on drying at 100°C. it gives up more water and acts as a binding agent to the other constituents of the clay. It ultimately (above 1000°C.) becomes, like kaolinite, a mixture of mullite and tridymite or crystobalite. It gives white bodies at all temperatures.

Damp halloysite shrinks enormously during air and steam drying, and again on firing, and it is to the presence of much halloysite that ball clays and other plastic clays owe their excessive shrinkage. Unlike kaolinite it is completely decomposed by boiling strong hydrochloric acid.

No satisfactory method for the determination of the actual percentage of halloysite in a clay has ever been worked out. It appears probable, however, that an approximate calculation might be made from either the molecular

* S. Sato *Jour. Chem. In. Japan*, 1918, XXI., 631.

† Hyslop & Rooksby (*Trans. Cer. Soc.* XXVII., 96) give a somewhat different scheme of alterations, viz.:

Up to 550°	Kaolin stable.
550 - 870°	Alpha crystals stable (? $Al_2O_3.2SiO_2$).
870 - 990°	Alpha disappearing, mullite and beta crystals forming (?$Al_2O_3.10SiO_2$).
990 - 1060°	Beta and mullite stable.
1060°	Beta disappearing, mullite and crystobalite stable.

ratio of alumina to water, or from the solubility in strong hydrochloric acid or from the absorption of malachite green or other suitable dyes. From the figures obtained in the Government Laboratory it appears that one gram of halloysite will absorb about 0.4 grammes of malachite green, from which the percentage of halloysite equals the Ashley figure divided by 8, when halloysite is the colloid present.

Quartz.—Silica, SiO_2. Quartz in angular or rounded grains, varying in size from several millimetres to a small fraction of a millimetre, is a constituent of all clays to a very variable extent. Natural mixtures of kaolinite and halloysite with quartz are found with quartz in all proportions from 1 to 99 per cent. The coarser grains constitute almost the whole of the natural "grit" of clays.

Pure quartz is colourless or milk white and retains its white colour when burnt. It melts at about 1700°C.; no exact temperature, however, can be fixed, as quartz over a range of about 100°C. passes through all stages of deformability lying between isotropic solid rigidity and viscous fluidity, besides which, if the rise in temperature be slow, molecular readjustments take place.

No chemical changes occur in the heating of quartz, but three molecular rearrangements take place as follow:—*

Up to 575°C.—Alpha-quartz with density 2.65.

At 575°C.—Change to beta quartz with density 2.63. Small expansion in volume (0.7%).

At 870°C.—Change to tridymite (Beta-2) with density 2.323. Expansion 13.2 per cent. by volume.

At 1470°C.—Change to crystobalite (Beta) with density 2.21. Further expansion of 5 per cent.

Total expansion from alpha-quartz to beta crystobalite is 20 per cent. of the original volume.

Because of its expansion, quartz is of great value in a clay as a corrective of the shrinkage of kaolinite and halloysite, and is purposely added with this object to many ceramic mixtures.

Though chemically stable by itself, on heating in association with other constituents of clays, many chemical reactions take place, especially with salt, iron compounds and calcite.

The proportions of quartz present in a clay, and the coarseness of the individual grains, are prime factors in determining the applicability of individual clays to industrial purposes. In fine ware, only grains less than 0.1 millimetre are permissible, coarser grains having to be screened out or ground down to this limiting size. On the other hand, particles as large as 5 to 10 mm. in diameter are often admissible in coarse refractories.

Muscovite.—Potash mica. Hydrous silicate of potassium and aluminium, $2H_2O.K_2O.3Al_2O_3.6SiO_2$. Minute scales of this crystalline mineral are always present in appreciable quantities in clays. These are often primary constituents of the clays, derived from the rocks whose disintegration has provided the material for the clay deposit. At other times they are

* See J. W. Mellor, "Treatise on Inorganic and Theoretical Chemistry," Vol. VI., p. 242.

secondary, generated in the clay bed during the passage of geological time, by interaction of halloysite or kaolinite with potash compounds in solution in the ground water. The chief difference between the soft slates, sometimes used in brickmaking, and a recent shale or bedded clay, is that in the former, all or almost all of the original halloysite and kaolinite has been converted mainly into muscovite, but partly also into chlorite. Most of the so-called felspar of clays is really a mass of microscopic scales of mica, keeping the external form of a felspar from which they have been derived.

The muscovite of clays is usually almost pure white, but may be slightly tinted by iron. On burning, a white or almost white body results.

Important chemical changes take place in heating muscovite. At 350°C. one quarter of the water is lost and at 800°C. the remainder evaporates. Somewhere below 1180°C., the mineral breaks up into a mixture of tridymite and orthoclase (felspar).* At about 1200°C. the orthoclase melts and binds the whole mass into a steel hard impervious porcelain. This mixture only flows as a whole at about 1400°C.

The practical and industrially important effect of an appreciable amount of mica in a clay is to bind it during burning, and render it steel hard and more or less impervious at the comparatively low temperature of 1200°C. It is therefore to be looked upon as one of the most useful and universal fluxes for the more refractory constituents of a clay.

Limonite.—Hydrated oxide of iron, $Fe_2O_3.H_2O$† is the chief colouring agent of yellow, pink, brown and red clays. It is probably part crystalline, in part non-crystalline, often possessing the properties of a hydrogel, and giving under suitable circumstances (e.g., in the presence of protective and dispersive colloids) colloidal suspensions and slimes which add to the plasticity of the clay in which they occur and help to bind them when drying. At other times limonite forms hard gritty grains or pebbles in clays.

Limonite is of practical importance in two different ways. Firstly it is the chief colouring agent of clays and clay products. Burnt by itself it loses its water at a low temperature and burns to various shades of red, losing oxygen and passing into magnetic oxide, Fe_3O_4, between 1200° and 1350°, and melting ultimately at about 1500°C. Burnt in conjunction with other clay constituents it gives compounds with various shades of yellow, pink, red, brown, grey and black.

Secondly, it is a powerful flux, yielding compounds with other clay constituents, especially quartz and alkalies which are freely fluid at temperatures of 980°C. upwards. Thus $NaFe'''Si_2O_6$ melts at 980°C.; Fe''_2SiO_4 at 1100° and $CaFe''Si_2O_6$ at 1140°C. These fluid compounds bind the whole mass together into a hard impervious mass, a considerable shrinkage accompanying the process. Local concentrations of such easily fusible combinations are the cause of the unsightly black or dark brown spots in bricks of various types, and of the small dark specks seen in white and cream coloured ware.

* Some authorities say they change into leucite and sillimanite. Leucite has the formula $K_2O.Al_2O_3.2SiO_2$, with a melting point variously determined at 1305° to 1430°C.

† Recent work has indicated the chemical identity in composition of limonite with goethite, both having the formula given above.

Minor Constituents.

Salt.—Chloride of sodium, NaCl. In countries possessing a high average rainfall and good drainage, the percentage of salt in any local clay would be quite inappreciable. For this reason we find practically no reference to its presence in, or effects on, ceramic materials in any of the recognised authorities.

In extra tropical Western Australia on the other hand, there is a very large area, with a rainfall of 15 inches or less per annum and with such slight gradient towards the sea as to be devoid of well defined drainage channels. Furthermore much of it has within recent geological times (Miocene period) been under the ocean, during which time the weathered zone was thoroughly impregnated with common salt and other oceanic salts. The result of this is that whilst most of the clays which occur close to the western coast, where the rainfall is high, and the drainage usually good, are as free from salt as most British and foreign commercial clays, those which occur beyond this limited region contain sufficient salt to seriously affect their ceramic properties. A maximum of 7.37 per cent. of water-soluble salts, of which 5.95 per cent. was common salt, was found in a white clay from Kanowna. This, however, is quite exceptional, the usual amount found being less than one per cent.

Salt, even in quite small quantities, however, exerts an extremely deleterious effect upon clay. In the raw state it reduces the plasticity by coagulating the colloids. On drying a modelled article, the salts concentrate at the surface and in quantities of 2 per cent. or more, fret the surface during crystallisation. Again, salt is by far the most powerful of all fluxes found in clay, quantities as small as 0.5 per cent. reducing the vitrifying point by 100 or more degrees. The fluxing effect is due to its melting at 800°C. and thereafter combining with the free quartz and silicates of the clay to form one or more of the following readily fusible compounds, with simultaneous evolution of chlorine gas.

$Na_2Si_2O_5$	Melting point	874°C.
$NaFe'''Si_2O_6$	,, ,,	980°C.
Na_2SiO_3	,, ,,	1090°C.*
$NaAlSiO_4$	,, ,,	1170°C.
$NaAlSi_3O_8$	,, ,,	1220°C.

Since during drying the salt becomes very unequally distributed through the body, the fusibility is similarly uneven, being greatest at the surface and at sharp edges, where evaporation deposits it from solution. This low fusibility of the surface, combined with the evolution of chlorine at the fusion point, is responsible for serious blistering whenever the proportion of salt in the clay rises above 0.5 per cent. Abundant instances of this effect have been met with during the course of this research and illustrations of typical cases are to be seen in the accompanying figures.

A further evil effect of salt is the transference of iron during burning from iron bearing material such as the walls of the kiln or ferruginous clay articles, to articles devoid of iron, which would otherwise burn white. This effect is due to the chlorine from the salt converting ferric oxide into volatile ferric chloride which circulates round the kiln and forms dark coloured ferric silicates on surfaces of suitable temperature and composition.

* Eutectic of Na_2SiO_3 with $CaSiO_3$, 1060°. (Morey & Bowen Trans. Soc. Glass Tec. IX. (1925) 247).

All things considered, common salt is by far the most deleterious constituent ever found in clays and one which needs removal by weathering or washing, whenever it exceeds 0.3 per cent. in amount. In testing local clays its determination is the first test to be applied, and if present in more than this amount a thorough washing always precedes the burning tests.

The known beneficial effects of weathering a clay are partly attributable to the complete removal of salt and other water soluble compounds which prevent dispersion of the colloids, and so lower the plasticity of the clay.

The removal of salt on a commercial scale would be effected by weathering in the open, or by filter pressing a suspension of the clay in water.

Calcite.—Carbonate of calcium, $CaCO_3$. This is an appreciable and often prominent constituent of many English and foreign clays, but appears to be totally absent or almost so, from all the Western Australian clays so far examined. Concretions of calcite have, however, been encountered in some abundance in a terra cotta clay at Belmont.

Calcite breaks up at a red heat into lime and carbonic acid gas. The lime thus formed is highly infusible by itself, but in contact with quartz and various silicates forms compounds with comparatively low melting points, for example $CaFeSi_2O_6$ and $CaNa_2Si_2O_6$ both melt at 1140°C., $Ca_3Al_2Si_3O_{12}$ at 1200°C., $CaMgSi_2O_6$ at 1310°C., $CaAl_2Si_2O_8$ at 1320°C. and $CaSiO_3$ at 1340°C. *The effect of calcite in a clay is therefore that of a flux, reducing the softening and flowing temperatures, and hardening the bodies and making them denser.

Felspar.—(Orthoclase or Microcline): Silicate of potassium and aluminium, $K_2O.Al_2O_3.6SiO_2$. Some soda invariably displaces part of the potassium. This is usually considered to be a frequent and important constituent of residual clays, and in calculating the mineral constitution of ore from its chemical analysis, the whole of the potash (and soda) is often calculated as orthoclase. This is quite justified in dealing with "Cornish stone," a partly kaolinised granite, whose equivalent has not yet been worked in Western Australia. But in the examination of the many clays dealt with in this address, and including many residual clays, undoubted felspar was only observed in one or two instances. Nothing at all like felspar could be detected in the majority of them, and material resembling felspar at first sight, when separated from others, was found in every case to be mica pseudomorphous after felspar. The alkali bearing mineral in all the sedimentary clays examined and in the great majority of residual clays was muscovite mica.

Felspar is a most important flux when present in such material as "Cornish stone," or when artificially added to a clay mixture. It melts at about 1200°C. to a tough white or greyish white enamel.

Humus.—Mixture of various compounds of carbon, hydrogen, nitrogen and oxygen resulting from the recent decay of vegetable matter. This occurs in appreciable amounts in all surface clays, and clays of very recent geological age. Consisting almost wholly of colloidal matter, much of which acts as a dispersive colloid on the inorganic hydrogels of the clays, it has an appreciable effect in the direction of raising the plasticity of clays. Like coaly matter too, it increases the porosity of the burnt bodies. Though often responsible for a dark colour in the raw clay, this colour is lost on burning by

* C. Doelter, H. B. der Mineral Chemie, 1, 658; Money & Bowen (1925) and others.

the complete combustion of the humus. A clay of grey colour in the raw state must not therefore be condemned for use in making light coloured ware, but judgment should be withheld until burning tests have been made.

Coal Substance.—Mixture of various compounds of carbon, hydrogen, nitrogen and oxygen. The humus of recent clays loses with passage of geological time, certain volatile constituents, and becomes of the nature of lignite, brown or bituminous coal. Such material is found in shale beds of past geological ages and is specially plentiful in the bedded clays (shales) of the Permian and Carboniferous formations, e.g., those of the Collie district. The presence of this material increases the porosity of the burnt body, but does not necessarily stain it, as the coloured carbon compounds, under normal conditions, completely burn out of the clay mixture in the kiln.

In some countries, for certain purposes a reducing atmosphere is maintained in the kiln so as to prevent the oxidation of the carbon.

Coaly matter is of practical importance to the potter, in that it consists partly of colloidal substances, some of which act as protective and dispersive colloids, to the halloysite and kaolinite of the clays, thus adding to their plasticity. Further, in burning such clays, local heat is generated in actual contact with the clay and the final removal of the coal substance by combustion leaves the body more porous that it would otherwise be.

A clay which in the raw state is very dark coloured from the presence of coaly matter may burn to a white or almost white body. This is true of some Collie clays.

Chlorite. Hydrous silicate of aluminium, magnesium and iron. $x(2H_2O.2MgO.Al_2O_3.SiO_2) + y(2H_2O.3MgO.2SiO_2)$. This is a minutely scaley, green mineral found in small proportions in the older shales and slates (e.g., Cardup-Armadale) as well as in the completely kaolinised greenstones. It acts as a flux, and as a red, brown or black colouring agent.

Opal. Hydrous silica, $3SiO_2.H_2O$. This occurs in traces on some residual and other clays, hardening them somewhat and making them difficult to disintegrate, besides reducing the plasticity. It loses part of its water at 100°C. and most of the remainder between that and 400°C., thereafter acting as quartz.

Gibbsite and Cliachite.—Aluminium hydroxide, $Al_2O_3.3H_2O$. Both minerals have the same composition, but Gibbsite is crystalline whilst Cliachite is a hydrogel. They are of rare occurrence in true clays and in Western Australia have as yet only been detected in one from Bolgart. As, however, nearly all our residual clays are covered with a crust of laterite composed of ironstained Gibbsite and Cliachite, small fragments of these minerals are liable to find their way into commercial parcels of clay. The chief effect produced is ascribable to the iron (limonite) content which gives fused slag spots in the finished ware, particularly noticeable in our local firebricks. Pure Gibbsite and Cliachite are dehydrated at a comparatively low temperature, yielding anhydrous alumina which only melts at about 2000°C., but in the presence of siliceous material is converted into mullite ($3Al_2O_3.3SiO_2$) at a much lower temperature.

Constituents Rarely Present in Quantities Exceeding One Per Cent.

Pyrite, Marcasite. Two varieties of sulphide of iron, FeS_2. Small concretions or disseminated grains of one or other of these minerals are not uncommon in carbonaceous shales protected by a fair thickness of over

burden, *e.g.*, some shales in the Collie coal basin and Swan Coastal Plain. They are objectionable constituents, as they are always irregularly distributed and during burning lose their sulphur and become oxidised to ferric oxide which acts as a strong local flux and pigment. They are absent from clays to which the air has a free access, and usually from those devoid of carbonaceous matter.

Rutile, Brookite and Octahedrite.—These three are different forms of titanium oxide, TiO_2, all of which have been detected in local clays. For example, octahedrite in the heavy concentrate from clay from Kunjin; brookite in the same from Yuna, Carmel and Victoria Park; and rutile in the same from Collie, Donnybrook, etc. In all cases the total proportion present probably does not exceed one tenth of one per cent. Titanium dioxide even in small quantities is said to give a faint yellowish tint to an otherwise white body.

Doelterite.—Hydrated oxide of titanium, $TiO_2.H_2O$. This mineral usually accounts for the greater part of the titanium found in the analyses of recent surface clays. In these it may occur as a fine powder, evenly distributed and forming up to one per cent. of the whole mass. In the laterites, fragments of which are apt to contaminate the underlying residual clays, doelterite forms from one to five per cent. of the whole. From the potter's point of view, it is chiefly of importance because of its suspected tinting capacity.

Ilmenite.—Titanate of iron, $FeTiO_3$. This hard crystalline mineral occurs in many sedimentary clays in the form of small heavy black grains which are readily detected during the mechanical analysis. It is never present to the extent of more than a fraction of one per cent., and in red ware or coarse ware of any kind is negligible. In white ware clays, however, it is a serious impurity, as it is one of the chief causes of the small black specks often appearing in such ware. It is a strong colouring agent and a flux, and can only be removed by electro-magnets, or electro-osmosis, or by careful levigation.

Siderite.—Carbonate of iron, $FeCO_3$. Small quantities of this compound exist in some Collie shales and in others of the older bedded shales of Carboniferous, Permian and Mesozoic ages. On burning, the carbonate is oxidised to ferric oxide, which acts as a flux.

Zircon.—Silicate of zirconium, $ZrSiO_4$. This heavy, hard crystalline mineral is found in small quantities in the heavy concentrates from most Western Australian clays. Its effect from a potter's point of view is negligible.

Gypsum.—Hydrous sulphate of lime, $CaSO_4.2H_2O$. Small quantities of this colourless and water soluble compound are found in saliferous clays and are said to be responsible for the greater part of the unsightly white scum which develops on the surface of some red bricks. As gypsum is water soluble, it can be removed if necessary from the raw clay by weathering or artificial washing. It is rarely, however, present except in quite small quantities.

Alunite.—Hydrous sulphate of potassium and aluminium. $6H_2O.K_2O.3Al_2O_3.4SO_3$. This occurs disseminated or in nodules in almost all the commercial clays raised at Kanowna. Alunite on heating to a temperature of 420°C. loses two-thirds of the water, and at 525°C. the balance. At 800°C. three quarters of the sulphuric oxide is split off, the balance being

lost at about 950°C. with the formation of potassium aluminate, or alumino-silicate if silica is present. In small proportions in a clay it has been found to act as a harmless flux.

Doubtful Constituents.

Magnesium silicates.—The analysis of practically every clay indicates the presence of quantities of magnesium ranging from traces up to one per cent. or even more. Only rarely does one find no magnesia whatever, local examples being washed kaolin from Glen Forrest, and the Bolgart, Mt. Kokeby and Elgin white sedimentary clays. In the older bedded rocks used for ceramic purposes such as the Gosnells-Cardup slate, the magnesia has been proved by microscopic examination to be present in chlorite. In the more recent calcareous sediments, such as those of Dongarra, it is probably present as a carbonate associated with calcium carbonate. In the majority of clays, however, it appears to exist as a silicate whose mineralogy has not yet been worked out. Recent work, both in Australia and abroad leads to the belief of the existence of the hydrogelatinous or colloidal magnesium silicate $H_4MgSi_3O_9+2H_2O$* isomorphous with halloysite, $H_4Al_2Si_2O_9+2H_2O$, and occurring frequently in intimate conjunction with it in various proportions. This mixture is especially noticeable in many bentonites, and fullers earths (*e.g.*, that from Watheroo), and is the basis of such clay-like "minerals" as montmorillonite †, saponite, etc. Such minerals increase the plasticity of clays greatly and their fusibility somewhat.

Sepiolite, $2H_2O.2MgO.3SiO_2$, and talc $H_2O.3MgO.4SiO_2$ are suspected of being present in some clays.

Vanadium Silicate.—A complex silicate containing vanadium, probably vanadiferous muscovite, is present in very small quantities in many clays. It is best detected by burning a briquette of the clay between 1100° and 1200° C., just saturating it when cold with water, and then setting aside to dry. During the burning the vanadium is converted into potassium vanadate, a water soluble salt of a brilliant yellow colour, which dissolves in the added water and is brought out on the surface during drying, remaining as a brilliant yellow stain. In the presence of abundant dust or other reducing agent the stain may be greenish yellow or green. The same stain is sometimes produced on a stack of bricks wetted for the first time by a shower of rain and then dried again by the sun. In this State it is often observed on the surface of the Glen Forrest firebricks (made from kaolinised granite and dolerite) and the Albany house bricks (made from a Miocene sediment). In the laboratory it has been observed on briquettes made from a large number of light coloured clays of all types. It was extremely strong on a white burning clay of doleritic origin from Balkuling (L. No. 9637E), and quite distinct on many others including No. 1121/25 Boyup Brook; Nos. 1329/23 and 2222/23 Quairading; No. 2016E, Jacob's Well, etc.

TEXTURE OF CLAYS.

The texture, or mechanical composition, of a clay is its constitution in terms of the sizes and forms of its individual grains, irrespective of their chemical composition. The finer types of ceramic ware can only be made

* This might conveniently be known as picrocollite.

† A mixture of equal molecules of halloysite and picrocollite has the composition $4H_2O.MgO.Al_2O_3.5SiO_2+4H_2O$, which is exactly the formula deduced by Ross and Shannon for montmorillonite which they consider to be the chief constituent of bentonite (*Jour. Am. Cer. Soc.* IX, 89).

up of bodies whose individual particles will all pass a 100 to 200 mesh screen, *i.e.*, whose particles are not more than 0.05 to 0.15 millimetre (0.002 to 0.006 inches) in diameter, whilst the coarsest ware, such as bricks, can be made of clay with certain proportions of particles one hundred times as large as this. In consequence the texture of a clay has a marked bearing upon its possible application, more particularly as only a limited amount of grinding, sifting or elutriation is economically permissible.

In the Western Australian Laboratory it has been customary to determine the grain size by levigation of the finest particles and sifting of the coarser. Each clay is thus divided up into five fractions, viz.:—

1. Clay substance.
2. Grit under 90 mesh (0.18 mm.).
3. Grit under 60 mesh (0.26 mm.).
4. Grit under 30 mesh (0.60 mm.).
5. Grit over 30 mesh.

The methods by which these are determined are given in a subsequent chapter (p. 206). The clay substance is the finest grained material capable of remaining in suspension in water for several minutes.

As examples of the wide ranges in texture found amongst local clays the following may be taken:—

China clay prepared on a large scale in the laboratory by levigation of Glen Forrest kaolinised granite was composed entirely of particles under 200 mesh (0.05 mm.), *i.e.*, "clay substance." Analysis showed that this clay substance comprised 91 per cent. kaolin and halloysite, 5 per cent. mica, 3 per cent. quartz and 1 per cent. moisture.

The completely kaolinised granite from which this china clay was prepared had the texture shown in "B." This is used in making firebricks and lumps.

The associated kaolinised dolerite (epidiorite) mixed with "B" for making refractories, had the texture shown under "C."

Mark	A.	B.	C.	D.	E.	F.	G.
Clay	China clay.	Kaolinised granite.	Kaolinised dolerite.	Sedimentary fireclay.	Semi-ball.	Ball.	Fuller's Earth.
Locality	Glen Forrest.			Collie.	Mt. Kokeby.	Kalamunda.	Collie.
Clay substance ...	100	59	97	66	91	95	99
Grit —90	...	1	1	25	9	2	1
Grit —60	...	3	1	9	Trace	2	Trace
Grit —30	...	6	1	Trace	Trace	1	Trace
Grit +30	...	31	Trace	Trace	Trace	Trace	Trace

A sedimentary fireclay from Collie with a high proportion of fine grit (quartz) is shown under "D."

A white sedimentary semiball clay from Mt. Kokeby is given under "E" and a ball clay from Kalamunda under "F." Both of these are levigated and screened during the manufacture of white semiporcelain.

A Collie fuller's earth of extremely fine grain is shown under "G."

As regards the shape of the particles, this is usually noted in regard to the grit fractions. If these consist largely of fine scales of mica, a much smoother finish is obtained on such an article as a roofing tile than if they consist mainly of angular quartz grains.

SUBSIDIARY CERAMIC MATERIALS IN WESTERN AUSTRALIA.

Several mineral substances are used by potters to modify the properties of natural clays as exhibited both in the raw working and burning. Those in commonest use are china clay, "Cornish stone," flint (quartz) and felspar. Of more restricted use are bone-ash, beryl and various minerals, required in the manufacture of refractory bricks and blocks.

China Clay.—The world famous "china clay" of Cornwall, known also as "washed kaolin" is almost pure kaolinite ($Al_2O_3.2SiO_2.2H_2O$) mixed with some equally valuable halloysite ($Al_2O_3.2SiO_2.2H_2O+2H_2O$), and obtained by sluicing and levigating completely kaolinised granitic rocks. It is added to crude clays, or used in place of them, not because of its plasticity which is of a low order, but because of its softness and extremely fine grain, and its pure whiteness after burning. The addition of it to a ceramic mixture improves the smooth working of the clay, gives a fine finish to the ware and finally ensures the whiteness of it. The Cornish mineral is largely used in England, Europe and America, and is regarded as the standard of what a washed kaolin or high grade kaolinite should be.

There is no reason why South-Western Australia should not become the Cornwall of Australia. The knowledge of our clay resources acquired during the last twenty years establishes the fact that in this part of the Commonwealth there is a very large area (about 20,000 square miles) of granite seamed with dykes of dolerite, or derived epidiorite, and partly overlain by a thin layer of laterite or sand. This granite and its accompanying greenstones are in many localities, some of them close to Perth, completely altered, for 20 feet or more below the overburden, into soft white clayey masses, from which all the iron has been leached and drawn to the surface to form laterite. In the case of the greenstones, the rock in mass consists of 80 to 93 per cent. kaolinite and halloysite, the balance being finely divided quartz and mica. Such a rock on washing will yield 85 to 95 per cent. of high grade china clay. In the case of the granites, a large proportion of coarse quartz granules is always present, the content in kaolinite plus halloysite being 45 to 60 per cent. The yield of excellent china clay from such a rock will be from 50 to 65 per cent. whilst the residual quartz is suited for use as a "flint." The washed kaolin from either class of rock will run freely through a 200 mesh screen, and burns to a good white colour somewhat purer as a rule in the case of the granitic clays than the dolerite clays, which contain larger amounts of titanium and vanadium.

Some figures regarding actual samples of raw material are worth quoting: –

No.	Rock.	Texture.				
		Clay Substance.	Grit —90.	Grit —60.	Grit —30.	Grit +30.
1900/18	Kaolinised granite, Glen Forrest	65·3	4·3	2·2	3·9	24·3
1550/17	Kaolinised granite, Kalamunda	74·8	9·1	5·6	4·7	5·8
1766/18	Kaolinised granite, Kondut	54·8	2·5	4·2	10·2	28·3
1427/28	Kaolinised granite, Pingelly	58·2	4·8	3·8	6·6	26·6
2112/19	Kaolinised granite, Tenterden	52·0	1·1	3·7	11·5	31·7
3514/19	Kaolinised dolerite, Glen Forrest	96·9	1·2	1·1	0·5	0·3
4158/20	Kaolinised dolerite, Kalamunda	89·7	7·4	1·4	0·8	0·7
3819/20	Kaolinised dolerite, Cardup	93·3	2·3	1·9	1·9	0·6
4222/20	Kaolinised dolerite, Kunjin	95·2	4·0	0·4	0·3	0·1

The figures for "clay substance" give the approximate yield of washed China Clay.

Analyses:

The following analytical figures are typical:—

——	1900B. Washed kaolin from granitic clay Glen Forrest.	3514. Kaolinised dolerite, Glen Forrest.	3819. Kaolinised dolerite, Cardup.	4222. Kaolinised dolerite, Kunjin.
	Ultimate Composition.			
SiO_2	45·57	52·19	51·25	46·51
Al_2O_3	37·93	34·18	34·19	38·12
Fe_2O_3	·31	·64	·64	·40
MgO	Nil	Nil	Nil	Nil
MnO	Nil	Nil	Nil	Nil
CaO	Nil	Nil	Nil	·09
Na_2O	·11	·10	·16	·12
K_2O	·58	·51	Traces	·32
H_2O —	1·07	·50	1·23	·50
H_2O + ...	12·36	11·38	12·26	13·68
TiO_2	·22	·34	·45	·62
NaCl	Slight trace	·15	·15	·16
SO_3	Nil	Trace	Trace	·05
Other soluble salts ...	Nil	·02	·03	Trace
	100·15	100·01	100·36	100·57
	Approximate Mineral Composition.			
Kaolin	90·4	80·7	84·8	93·2
Mica	5·3	5·5	2·0	4·0
Quartz	2·8	11·8	10·9	1·5
Limonite	·4	·8	·8	·5
Salt	Slight trace	·1	·1	·2
Minor constituents ...	1·1	·5	·6	·5
Moisture	·2	·6	1·2	·7
	100·2	100·0	100·4	100·6

The area from which a production of china clay may be effected in the future is that part of the Darling Range immediately east of Perth and thence southwards. This is an area with a high rainfall, and consequent good water supply, whilst raw material for washing is abundant and easy of access.

South-Western Australia possesses a number of pure white sedimentary clays of very fine grain which are practically natural china clays.

Cornish Stone.—This partly kaolinised granite or pegmatite, found associated with china clay deposits in the West of England, is in high repute as a flux. Its fluxing properties are due to the high proportion of felspar and mica present in it, the usual content in potash being between 6 and 7 per cent.

So far no typical Cornish stone has been discovered in Western Australia, but there is little doubt that if some of the granitic clay pits were deepened or their floors bored, supplies of this valuable flux would be disclosed. In the meantime some of the highly micaceous white clays known on the Coolgardie Goldfields should be worthy of a trial as a substitute.

Felspar.—In default of Cornish stone, almost pure hand picked felspar is used in large quantities as a flux in Europe, America and Japan. There are two distinct felspars in use, viz., Microcline (potash felspar) and Albite (soda felspar). All microclines carry a little soda and many albites a little potash. Finegrained intergrowths of the two minerals are not uncommon and are known scientifically as "Perthite." Felspars do not melt sharply as the temperature rises, but soften over a range of about 50°C. and become fluid between 1140°C. and 1220°C. The presence of soda and potash felspar is said to raise appreciably the melting point, and the viscosity of the fused mineral. After fusion the mineral has an increased volume of 7 per cent.

Both felspars are found in commercial quantities in pegmatite veins, which in South-Western Australia are abundant in the granite masses, *e.g.,* at Mahogany Creek, Mooliabeenie and Jacob's Hill, or stretching out from them into the surrounding greenstones, as for example at Balingup, Londonderry and Ubini. Further afield there are immense quantities of high grade felspar, both microcline and albite, available at Wodgina, Tabba and other tin and tantalum fields in the north-west of the State. Many pegmatite veins are far too narrow to be worth working, others are unworkable because of the small percentage of felspar, or its small size, rendering hand picking too laborious and costly. In some places the felspars are too ferruginous to be used for white ware, a maximum content of 0.2 per cent. Fe_2O_3 being all that is permissible without running the risk of producing badly tinted ware. In Western Australia, however, many of our felspars are of excellent white or pale grey colour and unusually free from iron.

Tentative specifications for felspar for ceramic uses drawn up by Professor A. S. Watts in the United States in 1920* included the following provisions:—

> Potash felspar shall contain at least 9% K_2O, not more than 3% Na_2O and 1% CaO. The sum $K_2O + Na_2O$ to be at least 12%. Soda felspar shall contain at least 7% Na_2O, and not more than 3% K_2O and 2% CaO + MgO. The sum $Na_2O + K_2O$ to be at least 10%. Mixed or blended felspar shall contain at least 11% $K_2O + Na_2O$.

* *Jour. Am. Cer. Soc.* 1920 p. 722.

No standard for iron content is laid down, though this is of the highest importance to white ware makers.

These specifications were reviewed by a committee who reported in 1923.* This committee recognised four grades of felspar as follows:—

Grade.	K_2O	Na_2O	CaO.MgO	
A	Over 10	Under 3·6	Under 0·75	Potash felspar.
B	Over 9	Under 3·2	Under 1·00	Potash felspar.
C	Over 7·8	Under 2·8	Under 1·00	Potash felspar.
D	Under 3·0	Over 7·0	Under 1·00	Soda felspar.

Still no standard for iron was suggested.

Later in 1923†, J. Turner discussed requirements for this material and suggested a lower permissible total for alkalis, viz., 10%. Regarding colouring agents he said, "The analysis should give no more than a trace of iron or other darkening minerals, and when fused should be free from specks to anyone with good eyesight (not using a magnifying glass). The fused felspar should be white drifting towards the warmer cream suffusions rather than a cold bluish white."

It appears from these and other statements, that a pottery felspar is still considered to be of first class quality if it is associated with not more than 10 per cent. of white quartz, is free from coarse flakes of muscovite, and included grains of black minerals (biotite, iron ores, etc.), as well as from brown iron staining, the total iron content not rising above 0.2 per cent. of Fe_2O_3.

Analyses have been made of a number of Western Australian felspars suitable for pottery purposes and obtainable in commercial quantities. In comparing these with any specifications for felspar it is to be remembered that the local analyses were made on the pure mineral, whilst truck lots would invariably contain some associated quartz and probably small quantities of mica, etc.

WESTERN AUSTRALIAN FELSPARS.

Microcline.

Locality.	Mahogany Creek.	Payne's Find.	Londonderry.		Jacob's Well.	Balingup.	Pingelly.
			Foch Mine.	Haig Mine.			
K_2O ...	12·20	14·96	11·44	13·24	10·31	12·37	13·53
Na_2O ...	3·08	1·51	3·18	2·32	4·33	2·85	2·44
CaO ...	Nil	Nil	...	Nil	...	...	...
Fe_2O_3 ...	·10	·07	·07	·07	·13	·09	·12
Al_2O_3 ...	19·11	18·78	...	18·51	...	...	...
SiO_2 ...	65·46	64·40	...	65·00	...	...	...

* *Bull. Am. Cer. Soc.* 1923, p. 163. † *Bull. Am. Cer. Soc.* 1923, p. 367.

Albite.

Locality.	Jacob's Well.	Wodgina.	Ravensthorpe.	Ubini.
K_2O	·66	·18	·04	·14
Na_2O	10·77	11·06	10·83	10·98
CaO	·21	·22	Nil	·41
Fe_2O_3	·11	·03	Trace	·06
Al_2O_3	19·94	19·67	19·44	20·59
SiO_2	68·19	67·87	69·13	67·87

The analytical figures for the local microclines should be compared with the following published figures for foreign felspars largely used in the pottery industry.

Locality.	Rorstrand, Sweden.	Noresto, Norway.	Middleton, Connecticut, U.S.A.	Hybla, Ontario, Canada.
K_2O	11·83	11·41	11·89	10·00
Na_2O	2·96	3·67	2·98	3·48
CaO	·02	Trace	·04	·52
Fe_2O_3	·16	·08	·30	·22
Al_2O_3	18·53	20·22	18·63	18·01
SiO_2	65·56	61·70	65·18	66·82

The felspars used hitherto in the Perth potteries have been microcline from Londonderry and albite from Ubini. Other deposits with good commercial possibilities are those of microcline and albite at Jacob's Well and Toodyay, microcline at Balingup and Mooliabeenie and albite at Ravensthorpe. There are a number of other localities known, particularly on the Pilbara tinfields, but they are less accessible to the potteries. At all the places mentioned the felspars are characterised by their exceptionally white colour, and concomitant freedom from iron oxide.

Flint. Some variety of natural silica forms an invariable constituent of all pottery, as without it the shrinkage of the moulded ware would be excessive during both air drying and burning. In the case of the rougher wares, clays are chosen which already contain the necessary proportion of quartz. In the case of finer ware, with a base of washed kaolin and finely ground felspar or Cornish stone, it is necessary to add silica in the form of ground flint or quartz. In England and Western Europe, where flint is abundant and remarkably free from iron, this is the material almost solely used. In Western Australia flint is rare and not known in commercial quantities, but vein quartz and quartz sand of a high degree of purity are both very common.

Up till now quartz sand has been used in the local potteries, one source of supply being the extremely white and pure sand from Lake Gnangara, 10 miles north of Perth. Other suitable sands are known at Bassendean, Maddington, Gingin, Busselton and Albany, and doubtless there are many other equally valuable deposits not yet prospected, as surface sands of varying quality are prominent features of much of the coastal area of the South West. The best are often closely associated with swamps carrying peaty water, which has been responsible for dissolving out, or preventing the precipitation, of ferrous carbonate or ferric hydroxide, which contaminate the larger proportion of the local sands.

The following figures are typical of these sands:

Locality.	Gnangara.		Bassendean.		Maddington.	Gingin.	Albany.
Ignition Loss	·07	·84	·57	·03	·12	·10	·20
After Ignition—							
SiO_2 ...	99·64	99·65	99·80	99·83	99·80	99·91	99·00
Fe_2O_3 ...	·028	·034	·022	·007	·032	·014	·07
Grain Size—							
Over 1 mm.	Nil	Trace	·1	Trace	·2	Nil	Nil
„ ·75 mm.	·1	5·6	10·0	5·5	9·4	·2	Nil
„ ·50 mm.	·1	17·0	48·0	38·8	38·8	9·3	Nil
„ ·25 mm.	89·0	69·2	38·0	53·3	42·1	87·8	27·4
„ ·10 mm.	9·8	6·6	2·7	1·9	6·5	2·6	70·6
Under ·10 mm.	1·0	1·6	1·2	·5	3·0	·1	2·0

The granular quartz washed on a small scale from the kaolinised granites of the Darling Range is of excellent quality for pottery purposes, and would be available in considerable quantities were the China Clay industry ever established here. A typical sample was found to carry only 0.08 per cent. Fe_2O_3 with about 99 per cent. SiO_2, the grain size being: Over 1 mm., 0.4;, over 0.5 mm., 14.6; over 0.25 mm., 40.1; over 0.1 mm., 34.2; under 0.1 mm., 10.7 per cent.

Vein quartz low in iron and easily quarried is available on the lower slopes of the Darling Range at Gosnells. In many other parts of the South-West and Eastern Goldfields are quartz veins of suitable purity for use in ceramics.

At Kalgoorlie, Kanowna and one or two other localities are deposits of highly siliceous, fine grained, and pure white clays, which show no shrinkage on burning, and are eminently suited for use in white ware and other potteries as a substitute for flint.

No silica bricks have yet been made in the State, and so far the raw material of suitable quality has only been located at great distances from any manufacturing centre. Bedded quartzites from the Billeranga Hills near Morawa (270 miles by rail north of Perth) and the Eyre Range on the south coast are considered suitable for this purpose. Their compositions are:

	Billeranga Hills.	Eyre Range.
SiO_2	99·22	99·63
Al_2O_3	·32	·16
Fe_2O_3	·12	·11
FeO	Nil	Nil
MnO	Nil	Nil
MgO	·03	Nil
CaO	·01	·01
Na_2O	·22	·04
K_2O	Nil	Nil
H_2O —	·01	Nil
H_2O	·08	·06
TiO_2	·01	·05
	100·02	100·06

Magnesite.—This valuable material for the manufacture of refractory bricks, etc., has been found in a number of places in the State, and in four localities exists as workable deposits, viz., Bulong, Coolgardie, Waverley and Ravensthorpe. Of these the first-named is by far the most important. In each case the deposit consists of veins and nodules of white porcelain-like mineral in the weathered surface zones of serpentine rock masses. Other similar but unproved deposits occur at Eulaminna and Comet Vale.

By far the most extensive deposit known is that at Bulong. From an area two miles long by a quarter of a mile wide, and within a few feet of the surface, many thousands of tons are exposed. The veins range from a few inches to two feet in width, and in many of the excavations form quite 50 per cent. of the exposed face. The associated rock is comparatively soft serpentine which is readily separated. The magnesite is pure white in colour and carries 93 to 98 per cent. $MgCO_3$, with a maximum of about 2 per cent. $CaCO_3$ and rarely as much as 5 per cent. silica.

There are several commercial deposits close to Coolgardie under a cover of a few feet of soil. These appear to be capable of yielding a high tonnage carrying 97 to 99 per cent. $MgCO_3$, nil to 1 per cent. $CaCO_3$, under 0.1 per cent. Fe_2O_3 and under 1.0 per cent. SiO_2. The deposit at Waverley is similar, but more inaccessible. An analysis of the mineral showed 98 per cent. $MgCO_3$.

A few miles south-east of Ravensthorpe, surface boulders of white magnesite, derived from numerous shallow veins, are plentiful, and have been used both as a flux and in the manufacture of magnesite bricks for the local copper smelter. This magnesite averages 96.6 per cent. $MgCO_3$ and 2.5 per cent. $CaCO_3$.

Boulders of magnesite are plentiful over a long strip of the eastern Wheat Belt in the vicinity of Kulin and Bruce Rock. This is much nearer to Perth than any of the above-mentioned deposits, and, when the finest veins are opened up, may prove to be of importance. A typical sample from Corrigin had $MgCO_3$, 98.1 per cent.; $CaCO_3$, trace; $Fe_2O_3.Al_2O_3$, 1.00; SiO_2, 0.6. Another sample from Nungarin, where it is said to be plentiful, had $MgCO_3$, 96.3 per cent.; $CaCO_3$, 1.8; $Fe_2O_3.Al_2O_3$, 0.2; SiO_2, 0.6.

Magnesite brick is stated to soften at 1500-1700° and to melt at 1980-2100°.

Dolomite.—This useful refractory material has only been found in small quantities in the South-West, mainly in the Eyre Range, but among the Palaeozoic and older sediments of the North-West there are thick beds of dolomite rock, often transmuted into dolomitic marble. This is particularly the case in the Ashburton and Gascoyne watersheds, a region at present not within reach of manufacturers in industrial centres.

Typical examples are:

Dolomitic Rocks.

	Coorara (Mt. Edith).	Irregully Creek.	Wiluna (Bubble Well)
SiO_2	·23	3·14	6·99
Al_2O_3	·20	·02	1·88
Fe_2O_3	Trace	·33	·65
FeO	·15	·39	·52
MnO	·30	·68	·87
MgO	21·25	20·70	19·67
CaO	30·43	29·53	26·84
Na_2O	Nil	·05	·08
K_2O	Nil	·12	·52
H_2O + ...	·10	·22	·63
TiO_2	?	Nil	·04
SO_3	Nil	·13	·10
CO_2	47·44	44·89	41·80
P_2O_5	·10	·11	·05
FeS_2	Nil	Nil	Nil
	100·20	100·32	100·64

Dolomitic marls have been observed in the South-Western Division at Rockingham, Toojelup (near Woodanilling) and Country Peak.

Chromite and Chrome Spinel.—The former, often known as chrome iron ore or chromite, consists essentially of $FeO.Cr_2O_3$. In the latter, much of the iron is displaced by magnesium, and the chromium by aluminium.

These useful refractories are like magnesite, associated with serpentine rocks. Although such rocks are very widespread in Western Australia, only two deposits of chromite and spinel of workable dimensions have been reported. One lies a little east of Namban, a railway station 126 miles north of Perth; the other at Jimblebah near Murramunda at the far eastern end of the Ophthalmia Ranges. The composition of typical hand picked parcels from these two localities are:—

	Cr_2O_3	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	SiO_2	H_2O	Total
Jimblebah ...	46·16	10·89	2·78	20·48	·26	11·04	5·76	2·21	99·58
Namban ...	22·76	42·09	3·80	17·45	·26	13·65	Nil	Nil	100·01

Scientifically the Jimblebah mineral would be classified as Beresovskite*, the Namban one as Ceylonite. Both are highly refractory, the softening point under load, and fusion point being recently given as 1510° and 2050° for chromite brick with 44% Cr_2O_3; and 2000° and 2130° for spinel brick.

Bauxite.—This rock consists essentially of one or more aluminium hydroxides, usually contaminated with iron hydroxide. Rather low-grade bauxite is abundant as a ridge-capping, one to six feet thick, over many parts of the Darling Range. The relative proportion of aluminium hydroxide and iron hydroxide varies greatly in these beds from point to point. It is only those portions which are high in alumina and low in iron that are of value to the ceramic industry. The Darling Range bauxite is a moderately tough rock, looking like an iron-stained conglomerate; the "pebbles," however, are nearly all concretions of limonite. These nodules are embedded in a fine-grained bauxite matrix varying in colour from red to pale yellow. The lighter coloured rock is usually the richer in alumina.

So far the Darling Range bauxite has only been used as a road ballast, but as several railways traverse the range, making the deposits very accessible, there is every reason to believe that in future they will be used for higher purposes.

The most important localities are Toodyay with Al_2O_3, 37 to 48 per cent.; Wooroloo, 38 to 48 per cent.; Sawyers Valley, 37 to 52 per cent.; Mahogany Creek-Glen Forrest, 27 to 50 per cent.; Kalamunda-Walliston, 24 to 45 per cent.; Clackline (one sample) 43 per cent.

Average high-grade rocks from Wooroloo (1) and Sawyers Valley (2) contain:—

	Al_2O_3	Fe_2O_3	TiO_2	CaO.MgO	Insoluble.	Ignition Loss.
(1)	43.39	17.72	1.46	Nil	13.40	24.04
(2)	51.82	9.35	.56	Nil	11.90	26.37

Graphite.—This mineral is found throughout the Pre-cambrian rocks of the State, but it is only the mineral which occurs in comparatively coarse flakes (over 0.1 millimetre) which is commercially valuable. Such graphite

* Beresofite, the name originally applied by E. S. Simpson to this mineral (Min. Mag. 19, 103) had previously been used for another mineral; Beresovskite is therefore substituted for it.

has been found in several places, notably in the Northampton mining district, and at intervals over a 300-mile east and west belt of country extending from the Oldfield River, west of Esperance, to the Donnelly River near Cape Leeuwin. The most important deposits along this belt are at Munglinup, Pallingup River and Kendenup.

In the Western Australian deposits no solid lumps of pure graphite are known similar to those found in Ceylon. The occurrences are of the Madagascar type, consisting of innumerable flakes and minute lenses of mineral along the planes of schistose igneous rocks. At the surface these are usually heavily impregnated with iron hydroxide and therefore incapable of concentration to the requisite minimum of 80 per cent. carbon. Below this gossan, which is never more than a few feet thick, the scaly graphite is found associated with bands of partly weathered rock which is easily concentrated, except in some instances where there is an intimate intergrowth of scales of mica and graphite.

The Government Laboratory is equipped with a model flotation plant for testing ores on commercial lines. Unless a yield is obtained of at least 10 per cent. of marketable flake, assaying 80 per cent. or over of carbon in scales not less than 0.1 mm. in diameter, an ore is considered valueless for the production of concentrates to be used in the crucible industry.

Some very good graphite has been got at Munglinup, a series of eleven samples showing a yield of 10.5 to 36.8 per cent. of flake with a maximum content of 93.2 per cent. of carbon and an average of 80 per cent. The Munglinup flake on the whole is coarser than that at Kendenup, where similar deposits have been opened up and a few tons of ore shipped abroad in the absence of any local dressing plant. The Kendenup deposits are close to the railway, only 50 miles from the port of Albany. The principal workings are on a band of weathered schist seven samples of which ran from 6 to 80 per cent. flake graphite. Concentrates from this mine have been very favourably received by crucible makers.

Beryl.—The use of this mineral in high tension electrical porcelain has recently been adopted. The mineral is a crystalline silicate found almost entirely in pegmatite veins, where it is usually associated with felspar of ceramic grade. In Western Australia it is found in several localities, notably Mt. Francisco, Wodgina, Yinnietharra, Poona, Melville, Balingup and Ravensthorpe. In all cases it would probably only pay to mine in conjunction with the associated felspar.

Andalusite, Kyanite and Sillimanite.—All of these are crystalline silicates of aluminium without water, which have been employed for the manufacture of special refractories and electrical porcelain in Europe and America. They are not common minerals, but in some parts of the world rock masses have been found consisting of 60 to 80 per cent. of these minerals and such rocks are used by ceramists in their entirety.

In Western Australia micaceous schists carrying in certain bands comparatively large masses of these highly refractory minerals are known.

In the lower Chittering Valley, 30 to 40 miles north-east of Perth, there is a very large area of sillimanitic and kyanitic rocks. A small prospect has been opened up at Goyamin Pool and from it 15 tons of 90 per cent. sillimanite taken out from segregations in a biotite schist alongside a dolerite dyke.

In the upper Chittering Valley, especially, there are large areas of kyanite rocks suitable for concentration.

At Clackline, 50 miles east of Perth, there is a large firebrick plant operating on a sillimanite fireclay.

At Wilgarup, 150 miles south of Perth, boulders of kyanite have been found, but not yet traced to their source. An appreciable quantity of these boulders has been collected and marketed.

Sillimanite bearing rocks are known to occur at Toodyay to a very limited extent, but no commercial exploitation of them has ever been attempted.

DESCRIPTION OF LABORATORY TESTS APPLIED.

The series of tests which have been applied to Western Australian clays was devised to satisfy the particular requirements of the times. These were designed to provide information of some practical value with apparatus that would not be too elaborate, spacious or costly.

The methods of testing any raw material are dependent on the methods of manufacture to be applied to it and its ultimate uses. The testing of clays, therefore, follows mainly on physical, rather than chemical, lines. Whilst clays are worked up in the raw state, the finished product has always passed through a process of burning. Having this in view, the series of tests is conveniently arranged under three headings:—

(A) the determination of the properties of the raw clay;

(B) the investigation of its behaviour during burning;

(C) the determination of the properties of the burnt clay, the burning having been made at several different temperatures.

The complete list of tests applied was:—

A. Properties in the Raw State:

(1) Chemical composition.
(2) Mineral composition.
(3) Mechanical composition or texture.
(4) Plasticity.
(5) Air shrinkage.
(6) Tenacity when dry.

B. Each clay was then burnt under various conditions of time and temperature, and its behaviour in the kiln was noted, after which the third series of tests was applied, viz.:

C. Properties in the Burnt State:

(1) Colour.
(2) Fusibility.
(3) Shrinkage.
(4) Porosity.
(5) Vanadium staining.
(6) Strength.
(7) Surface grain.

Details of the individual tests follow.

(A. 1) *Chemical Composition.*—Complete chemical analyses were made of such clays as appeared likely to be used for pure white or cream ware. The results were mainly used to calculate the approximate mineral composi-

tion, which is of the highest value in predicting and explaining the properties during and after burning, and in calculating the requisite addition of fluxes to produce a good porcelain or semi-porcelain body, etc. The proportions of oxides of iron and titanium present are of interest in determining the cause of a yellowish tinge developed on burning certain white clays. The determination of the common salt present is of the highest importance in view of the very deleterious effect of this compound on clays, and was therefore made on every clay before a burning test was made. The total water soluble salts content was also determined.

(A. 2) *Mineral Composition.*—This was calculated from the complete analysis after microscopical examination of the different grades obtained by elutriation. The method of calculation adopted was as follows:—

Chlorine was calculated to sodium chloride. The remaining sodium and potassium were added together and calculated as mica $(KNa)H_2Al_3Si_3O_{12}$ Titanium was calculated to ilmenite $FeTiO_3$, doelterite, H_2TiO_3, or to one of the mineral oxides TiO_2 according to the microscopic examination. The balance of the iron was stated as ferric hydroxide, $Fe_2O_3.H_2O$. The alumina remaining was calculated to kaolin, $H_4Al_2Si_2O_9$ and halloysite, the relative proportions of the two silicates being approximately estimated from the proportion of water and the Ashley plasticity figure. The balance of the silica was taken as quartz SiO_2.

The results of this calculation may not always be rigidly accurate, but they are usually very close to the truth, and give figures of great practical value.

(A. 3). *Texture or Mechanical Composition.*—The particles composing the clay were divided into clay substance and grit, the latter subdivided into sizes over 30, 60 and 90 mesh and under 90 mesh. These corresponded approximately to particles over 0.60, 0.26 and 0.18 millimetre, and under 0.18 millimetre diameter.

The clay substance was determined by dropping 100 grams of air dry, 10 mesh, clay in a slow and oscillating stream into a 800 ml. beaker full of tap water (pH8.4 ±). It was stirred well to dissolve soluble salts and two-thirds of the liquid decanted after 5 minutes settling. It was filled up with water and allowed to soak overnight, and then washed by repeated decantation after 90 seconds settling, each time, at least two inches of fluid being left in the beaker for the first few decantations, and thereafter, one inch. After each decantation the residue was roughly swirled to break up composite particles. The grit remaining was dried and weighed, and then sifted in the three screens mentioned. The clay substance thus obtained was mainly kaolin and halloysite, but included some very fine particles of other minerals, particularly microscopic grains of mica.

It is to be noticed that dispersion of the clay particles is almost impossible if the water is poured on to the raw clay, especially if the latter is already damp.

Some hard clays with small amounts of secondary silica or carbonates required rubbing up with a rubber pestle after the first few decantations, in order to break up composite particles.

(A. 4) *Plasticity.*—This capacity for moulding or shaping without cracking or relaxing is the characteristic property of substances in the plastic state, which may be defined as a state of matter intermediate between true

solidity and true fluidity, a substance in the plastic state being resistant to deformation by gravity or other moderate force, but deformable without cracking by more intense human or mechanical pressure. Plastic substances are essentially two or three component systems, requisite components being a fairly rigid granular base with a viscous fluid lubricant filling the interspaces, the lubricant acting also as an adhesive. In the case of potters' clays the base consists of granules of quartz, mica and kaolin, whilst the lubricant is a colloidal suspension of halloysite, and probably other substances in water.

From the practical point of view, plasticity is of the highest importance, as the capacity of a clay mixture for fine moulding will depend upon the plasticity of its components. It is probably governed by several independent factors, the principal one being the proportion of colloids and water present, others the size and shape of the individual particles. Many methods have been suggested for obtaining a mathematical statement of this property, none of which is exact, and it appears as if the only ultimate test of plasticity is the discrimination of the practical potter.

Assuming, however, that within the limits found in most light coloured clays, the plasticity is directly proportional to the percentage of colloids present, and making use of Ashley's work on the adsorption of aniline dyes by clay colloids * an empirical "Ashley's figure" has been largely used as the guide to the relative plasticity of fine pottery clays. This figure was only adopted for use after tests made by an experienced potter showed conclusively that the "Ashley figure" placed a series of clays in the same order of relative plasticity as did the practical modelling test. This figure was found by measuring the adsorption of malachite green oxalate by the colloids of a fixed quantity of clay. The method adopted was as follows:—

One gram of coarsely crushed malachite green oxalate was placed in a 500 mls. wide-mouthed bottle with 400 mls. of distilled water, and 20 grams of the clay added to it. The mixture was then shaken well at intervals for two or three hours, to ensure that all the dye was dissolved, and that the hydrogels were completely saturated with water. The suspension was allowed to settle overnight. Ten mls. of the water were drawn off and diluted to 100 mls.; 10 mls. of this again diluted to 100 were compared colorimetrically with 10 mls. of a standard solution obtained similarly but without the addition of clay. If they exactly matched no adsorption had taken place. If, however, 10 mls. of the solution from the clay was matched by "x" mls. of the standard solution then (10 - x) is a measure of the adsorption, and, expressed as centigrams of malachite green adsorbed by 20 grams of clay, was taken as the "Ashley figure."

Occasionally the Ashley figure exceeded 90. When this was the case, adsorption may not have proceeded to saturation point and the true figure may be over 100; a further 1 gram of malachite green oxalate was then added to the suspension and the shaking and settling repeated. Finally the solution was compared as before with the standard.

It would appear that the "Ashley figure" is vitiated by the presence of an appreciable amount of marly calcite, and to a less extent by colloidal ferric hydroxide, in both cases a high reading being obtained. The effect of the former when present was overcome by a preliminary shaking of the clay and water with 1 gram or more of sodium or potassium oxalate.

* *United States Geological Survey Bulletin* 388.

The "Ashley figures" given by typical classes of clay were:—

Abnormally quartzose or micaceous clays	1 to 20
Fireclays and washed kaolins (China clays)	20 to 40
Semiball clays	40 to 70
Ball clays and red brick clays	70 to 150
Fullers earths and bentonites	Over 150

Preparation of Clay for Moulding.—The crude clay (about 10 lbs.) was first air dried and broken gently to pass a 10 mesh sieve. The content of salt was then determined, and if over 0.3 per cent., a preliminary washing of the clay by decantation was made to remove the greater part of it. After this the clay was filtered and again air dried, crushed lightly to pass a 10 mesh sieve and well mixed.

For moulding, about one pound of the dry clay was taken, and water worked into it until it was distinctly softer than was necessary to mould easily. After working by hand for about half an hour, the wet clay was set aside overnight in a damp place to mature, i.e., to completely swell the hydrogels. In the morning it was again kneaded, a little more water usually having to be added to bring it to a suitable state of plasticity for moulding. Small uniform test pieces were made in a steel cylinder filled with two loose discs and with two weep holes of one-eighth inch diameter in the side. To obtain the test pieces the loose bottom disc was put in the mould (lightly oiled) and a roll of plastic clay pressed in and cut off at the upper level of the mould. The loose top disc was then put on and pressed in about one-eighth inch by hand, after which the top and bottom were further pressed in by an ordinary hand bench vice until clay projected from each of the weep holes. The pressure was relieved, the bottom removed and the moulded cylinder of clay forced out by a plunger.

(A.5) *Air Shrinkage.*—The diameter of the test piece was that of the mould, viz., 38 mm., and the height was immediately measured in mm. at a marked spot by a sleeve micrometer. The test piece was then immersed in petrol to remove most of the oil picked up from the mould, and set aside to dry at air temperature. After drying for about a week the diameter of the briquettes was measured in two directions at right angles to one another, and the height measured at the previous point. The average linear shrinkage per cent. was calculated from these measurements.

If D_1, D_2 and H were the original diameters (in two directions at right angles) and height and d_1, d_2 and h were the dried.

Then air shrinkage per cent. was—

$$\frac{(D_1 + D_2 + H) - (d_1 + d_2 + h)}{D_1 + D_2 + H} \times 100$$

Air shrinkages measured on Western Australian clays varied from under 1 per cent. for highly siliceous or micaceous clays up to 17 per cent. for highly plastic clays, the figure rising rapidly with increase in hydrogels and decrease in stable crystalloids like quartz. Some typical figures were nil for a kaolinised porphyry, 1.3 per cent. for a kaolinised granite, 3.6 and 7.2 for sedimentary fire clays, 11.8 for a ball clay and 16.3 for a red brick clay. Any tendency to warp during drying was noted at this stage.

For all classes of ware, but particularly for hollow ware, it is necessary to know the air shrinkage as well as the fire shrinkage so as to make the necessary allowances for size in designing and modelling. An air shrinkage

above 8 per cent. introduces such large differences in size between the modelled and finished article, as well as leading to warping, that clays with this property must be mixed with more siliceous or more micaceous material, or grog (previously burnt clay of the same type), before use.

(A. 6). *Tenacity when Plastic and when Dry.*—These are both worthy of careful measurement. It is desirable that this should be done in a machine of the cement type, as the plastic strength of a body is of prime importance in throwing clay ware. No such determinations were made in any of the tests carried out in the Government Laboratory owing to the absence of the necessary equipment. The dry tenacity is also important from the point of view of the capacity of moulded ware to stand handling during transportation to and from the drying chamber, and whilst packing in saggers and stacking in the kiln.

As the necessary facilities for obtaining a figure were not available these characteristics were tested roughly on one of the test pieces by determining the ease with which the edges could be broken and the surfaces rubbed off by the fingers.

(B.) *Burning.*—A large number of semi-commercial burning tests lasting over several days was made in a special kiln. The experience gained showed that practically useful and closely comparable results could be obtained by burning the above described test pieces in an assay muffle furnace over considerably shorter periods. The main observed difference between the two tests was that in the kiln, owing to the more gradual increase in the temperature, there was less tendency to crack during burning, whilst the final body was slightly stronger and less porous than that produced in the small muffle furnace.

The standard temperatures chosen for these tests were (950° and 1000° centrigrade for highly coloured clays), 1050°, 1150°, 1250°, 1350° and rarely 1400°. Higher temperatures than 1350° were seldom obtainable in a muffle furnace and were not required under the existing conditions of the trade in Western Australia as the manufacture of firebricks and fire lumps from local materials had already been well established. On the other hand special information was required in regard to our raw materials for making white ware and cream coloured ware (maximum temperature requirement about 1250°), vitrified sanitary ware (1350°) and roofing tile (1100°).

As the Department did not possess a pyrometer the indicators used were:—

950° Pure silver wire in a small coil resting in a depression of the surface of the briquette. Melting point 961°

1000° Alloy of 40% gold, 60% silver, in sheet. Melting point 1003°.

1050° Pure gold sheet used in the same way. Melting point 1062°.

1150° Seger cone No. 3a.

1250° Seger cone No. 8.

1300° Seger cone No. 10.

1350° Seger cone No. 12.

After steam drying the test pieces were heated for seven hours in a hot air oven to a maximum temperature of 210°C., followed by heating in an electric furnace for seven hours to a maximum temperature of 900° and then for a further seven hours to 1050°C., fourteen hours to 1150°, 21 hours to 1250° and 28 hours to 1350°. It was necessary to allow the furnace

to cool down overnight after each seven hours burning, those briquettes burnt to the desired temperature being taken out of the cold furnace in the morning.

There was little to note regarding the behaviour of the clays during the actual burning except in three regards. Highly plastic clays often cracked during the earlier stages of heating usually below the dullest red. This could be obviated by a thorough steam drying followed by slow heating in a hot air oven before burning, except in a very few instances of extremely plastic clays obviously unsuited for commercial burning without admixture with more siliceous and porous material. Highly salty clays could be seen to blister on the surface at temperatures above 1000°, and in some cases to swell up into pumice-like bodies. Finally, ferruginous clays were occasionally heated to a point at which they could be seen to start flowing.

(C. 1) *Colour of Burnt Body.*—The first test to be appplied to the burnt briquette was to examine its colour very carefully. In all but a few of the very purest white clays this was found to vary with the temperature of burning, being usually darker or more pronounced as the temperature of burning increased. Thus a clay which burnt to a pure white at 1050° might show a creamy tinge at 1150° and a still stronger cream tint at 1250° and 1350°. A clay which was only pale cream when burnt at 1050° would perhaps be a distinct buff, after heating to 1250° and 1350°. A coloured clay burning to a light red at 950° might be dark red after 1050°, liver coloured after 1150° and almost black after 1250°.

The colour assumed by a clay when burnt particularly at or about 1150°C., is one of the first characters to determine its range of utility. For white ware, the most valuable weight for weight of all ware, only clays burning at 1150° to a white or at most a very pale cream can be utilised, and other things being equal, the clay producing the whitest body at this temperature is the most valuable. For clays for white ware and cream coloured ware therefore, this temperature was chosen as the standard temperature for comparison. The white ware clays were graded into (1) pure white; (2) good white; (3) creamy white; (4) greyish white, according to their colour after burning at 1150°; the cream ware clays into (5) light cream; (6) strong cream; (7) light buff; (8) strong buff; (9) pinkish buff, after burning at the same temperature. Finally the strongly coloured clays were classified according to the colours developed at 1050° into (10) light and dark grey; (11) terra cotta and light red; (12) dark red and brown.

The selection of a standard for "pure white" presented some considerable difficulty. So-called white papers are all quite appreciably tinted, as also are all porcelain and semi-porcelain tiles, etc. Finally chemically precipitated calcium carbonate, precipitated basic magnesium carbonate, pure calcined magnesia, and a very pure surface magnesite in powder were used for comparison, especially the first and second named.

For all red and terra cotta ware a lower temperature of comparison, viz., 1050° was chosen, as such ware (house brick, agricultural drain pipe, roofing tile, etc.) is burnt somewhere round about this temperature. The briquettes burnt at higher temperatures were useful for determining the temperature required to produce clinkered or vitrified brick or tile, and the possible utility of the clay as a flux for stone ware, etc.

(C.2) *Fusibility.*—The temperatures at which some or all of the constituents melt to form a porcelain, slag or glass are factors of great practical importance. Clay mixtures seldom or never completely melt at a

definite point as do metals or ice, but usually show a progressive softening and increase of vitrification over a long range of temperature. To record the behaviour of a clay in this respect three stages were noted, viz.:—

(1) Incipient vitrification: This was the temperature at which the cold body first showed a hardness greater than that of penknife steel, indicating that the most fusible of the constituents had melted and bound the whole clay into a steel hard, but porous, mass. This frequently occurred at 1200° to 1250° when much mica or other flux was present.

(2) Advanced vitrification: This was the point at which the body had not only become steel hard but, by slight internal flow, had obliterated most of the pores, reducing the total porosity to less than 5 per cent.

(3) Flowing temperature: The point at which the briquette or other object showed general flow to the extent of losing its original outline.

(C.3) *Fire Shrinkage.* This important factor was determined by micrometer measurements of the burnt briquette or other test piece in a similar way to that described under Air Shrinkage (p. 208). The observed linear shrinkages ranged from a small negative amount (i.e., a slight expansion) up to as much as 17 per cent. in the case of Woodlupine ball clay (No. 2333E).

Very siliceous clays show only a minute shrinkage, or even a slight expansion rather than a shrinkage, between 800° and 1050° because of the alteration of quartz to tridymite. As an example No. 1860E, a granitic fire clay from Glen Forrest, with an air shrinkage of 3.9 per cent., showed a fire expansion of 0.6 per cent. at 1150°, and an expansion of 0.1 per cent. at 1350°. A fine grained siliceous clay from Kanowna (No. 1732E) showed only 0.1 per cent. shrinkage at 1050°, 0.3 at 1150°, and 5.1 at 1250°.

On the other hand a pure white and almost quartzless kaolinised dolerite from Glen Forrest (No. 1859E) with an air shrinkage of 9.2 per cent., showed an additional 4.6 per cent. at 1050°, 8.9 at 1150°, 14.4 at 1250° and 16.5 at 1350°. The corresponding figures for a similar Wagin clay (9000E), used commercially as a china clay, were 4.2 in air; 3.2, 4.8, 12.8 and 16.6 in the fire.

These high shrinkages are in practice avoided by suitable additions of finely ground flint or other highly siliceous or previously burnt materials.

The approach of the "flowing temperature" is indicated usually by a sudden increase in shrinkage. This is followed by a slight increase in volume when the viscous stage is actually reached, owing to the expansion of included gases, which are unable to escape once the surface has been completely converted into a viscous fluid.

(C. 4) *Porosity.*—The porosity of a burnt body is brought about by the independent shrinkages of its component particles during drying and burning. It varies with the temperature, decreasing as the latter rises, and falling to a very low point as complete vitrification is approached. It is determined numerically in order to decide whether the clay will give a vitrified impervious, or semi-vitrified body when burnt alone or whether fluxes will have to be added to effect this. In the case of tile and brick bodies exposed to the weather the porosity figures indicate their capacity to keep out damp and resist abrasion and should not exceed 15 per cent. Finally the

porosity figure at the highest temperature of burning (1350°) is an indication of the capacity of a fire clay to stand a higher temperature without failing. For example a Collie bedded clay (No. 1575E) showed a porosity of 25.3 at 1350° indicating that it was far below its melting point at this temperature.

The porosity is stated in terms of grammes of water absorbed per 100 grammes of burnt body. It was determined by weighing the dry burnt body, immersing it slowly in water, and alternately heating to boiling, and cooling to air temperature, three times. The saturated briquette was then again weighed and the percentage of absorbed water calculated.

Some characteristic examples of porosity figures are:—

No.	Clay.	Locality.	1050°.	1150°.	1250°.	1350°.	1400°.
1388E	Stoneware ...	Mundijong ...	16·0	7·2	6·3	3·2	Nil
1575E	Sed. fireclay ...	Collie	34·5	33·6	31·2	25·3	?
1166E	China clay ...	Kunjin ...	38·2	35·5	24·5	9·2	?

(C. 5). *Vanadium Staining.*—It is as the briquette dries, after saturation with water during the porosity test, that any staining due to water soluble vanadium salts becomes apparent. It appears as a canary yellow, orange yellow, or greenish yellow stain on the upper surface of the dried briquette, and occasionally is very pronounced. The white doleritic clays from Quairading-Jacobs Well district show it quite strongly. Such a stain might well affect the colour of the glaze of finished ware.

(C. 6.). *Strength.*—The strength of a burnt-body should be determined instrumentally to render the testing of a clay complete. In the series of tests carried out in the Government Laboratory a rough indication of it was obtained by scratching the surface with the finger nail or penknife and by endeavouring with the hands only, to chip off fragments from the arrises.

(C. 7). *Surface Grain.*—The final test applied to the burnt body was to examine closely the texture of the surface, noting whether it was extremely fine and smooth, or on the other hand, quite rough, granular and porous, or whether it had some intermediate quality. From this one could judge what sort of finish might be expected in articles made from the unground and unscreened clay.

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APPENDIX I.

Analyses of Western Australian Clays.

APPENDIX II.

Classification of Western Australian Clays.

APPENDIX III.

Localities of Clays Tested.

APPENDIX IV.

Physical Tests of Best Western Australian Clays.

APPENDIX I.

ANALYSES OF WESTERN AUSTRALIAN CLAYS.

No.	1	2	3	4	5	6	7	8	9	10
Locality	Yuna.			Bolgart.	Burabadji.	Armadale.	Cardup.			Campion.
Economic Class	I. A, Stone Clay.	IV. A(a), Ball Clay.	X. A(b), Stoneware.	II. A(a), Ball Clay.	I. A(d), China Clay.	Soft Slate.	Soft Slate.	Weathered Slate.	III. A(a), Ball Clay.	Miloschite.
	%	%	%	%	%	%	%	%	%	%
SiO_2	72·86	71·22	70·52	43·10	52·39	67·20	73·42	70·06	51·25	54·04
Al_2O_3	16·87	17·69	17·27	39·56	32·26	15·06	12·51	18·29	34·19	30·27
Fe_2O_3	·94	·27	1·70	·69	·56	n.d.	3·81	1·17	·64	·16
FeO	...	...	...	...	...	4·14	1·56	·40	...	·14
MnO	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	·05	·43	·07	...	tr.
MgO	·43	·30	·50	*Nil*	·16	2·43	1·91	·45	*Nil*	·31
CaO	*Nil*	·31	tr.	*Nil*	·04	·11	*Nil*	*Nil*	*Nil*	*Nil*
Na_2O	·22	·26	·14	·17	·29	·42	·86	·11	·16	·23
K_2O	1·16	·63	1·30	·64	·54	4·94	3·02	3·72	tr.	·14
NaCl	...	1·14	·61	·13	·58	tr.	tr.	·48	·15	tr.
TiO_2	·77	·46	·82	·44	·23	·46	·25	·74	·45	·31
CO_2	...	...	...	...	...	*Nil*	·02	·02	*Nil*	*Nil*
P_2O_5	n.d.	·25	·20	*Nil*	...	·01	·12	0·6	...	*Nil*
SO_3	·33	n.d.	·22	*Nil*	...	...	...	...	...	n.d.
H_2O + ...	5·62	6·91	6·24	14·49	11·69	3·39	2·38	4·17	12·26	11·89
H_2O —	·98	·51	1·28	1·03	1·42	·29	·12	·86	1·23	2·16
Humus	...	...	...	...	...	·46 †	·03 †	*Nil* †	*Nil*	*Nil*
Others	...	·43*	...	·08*	...	1·07 ‡	·00‡	·00	·03*	·80 §
Total	100·18	100·38	100·80	100·33	100·16	100·03	100·44	100·60	100·36	100·45
Analyst	Webb.	Gillies.	Webb.	Gillies.	Bowley.	Le Mesurier.	Murray.	Murray.	Bowley.	Hill.
Appendix IV. No. ...	..	...	...	39	24	...	...	...	71	...

* Water soluble salts. ‡ Pyrite. † Graphite. § Cr_2O_3 (In 10, V_2O_3 *nil*).

APPENDIX I.—ANALYSES OF WESTERN AUSTRALIAN CLAYS—*continued.*

No.	11	12	13	14	15	16	17	18	19	20
Locality	Clackline.		Collie.		Dongara.		Elgin.	Glen Forrest.		Stinkwell.
Economic Class	II. D, Kaolinised Sillimanite Schist.	? Stone Clay.	? Fire Clay (Shale).	III. A(d). Fire Clay (Shale).	? Brick.	? Brick.	II A.(a), Ball.	I A.(a), Levigated China Clay.	II A.(a), Fire Clay.	II A.(a), Semi-ball.
	%	%	%	%	%	%	%	%	%	%
SiO_2	63·83	51·55	51·95	54·31	62.74	45.74	49.08	47.57	52.19	48.07
Al_2O_3	26·24	33·25	29·58	28·32	13.32	11.01	34.58	37.93	34.18	35.96
Fe_2O_3	·60	·43	3·40	1·23	5.56	4.26	.43	.31	.64	1.00
FeO	*Nil*	*Nil*	n.d.	n.d.	n.d.	n.d.	*Nil*	*Nil*	*Nil*	*Nil*
MnO	*Nil*	*Nil*	tr.	·58	.45	.33	*Nil*	*Nil*	*Nil*	.01
MgO	·22	·40	1·01	·33	1.39	1.38	*Nil*	*Nil*	*Nil*	.28
CaO	*Nil*	·09	tr.	*Nil*	1.30	14.86	.04	*Nil*	*Nil*	.13
Na_2O	·09	·31	1·09	·11	.66	.54	.25	.11	.10	.06
K_2O	1·76	·11	·63	·39	3.46	2.09	.75	.58	.51	.54
NaCl	·03	...	present	·69	*Nil*	*Nil*	.36	*Nil*	.15	.08
TiO_2	·58	2·19	...	·56	.70	.51	.67	.22	.34	1.26
CO_2	·03	...	...	·26	.38	12.10	*Nil*	*Nil*	*Nil*	*Nil*
P_2O_5	·04	...	...	n.d.	...	...	n.d.	n.d.	...	.05
SO_3	·02	...	...	*Nil*	...	...	*Nil*	*Nil*	...	*Nil*
H_2O + ...	6·15	10·41	11·23	9·61	6.46	4.68	12.26	12.36	11.38	12.31
H_2O —	·60	·90	·54	2·90	4.16	2.68	1.43	1.07	.50	1.02
Humus	*Nil*	*Nil*	present	1·10	...	...	*Nil*	*Nil*	*Nil*	*Nil*
Others	...	V_2O_3 tr.	...	·16*	...	...	.11*	...	.02*	...
Total	100·19	99·64	99·43	100·55	100.58	100.18	99.96	100.15	100.01	100.77
Analyst	LeMesurier.	Williams.	Simpson.	Gillies.	Webb.	Webb.	Gillies.	Simpson.	Gillies.	LeMesurier
Appendix IV. No. ...	...	...	...	...	...	...	42	3	43	45

* Water soluble salts.

APPENDIX I.—ANALYSES OF WESTERN AUSTRALIAN CLAYS—*continued.*

No.	21	22	23	24	25	26	27	28	29	30
Locality	Jacob's Well.	Kalamunda.	Kunjin.	Moora.	Mt. Kokeby.	Mujar.	Newlands.	Newlands.	Perth.	Wagin.
Economic Class	I. C(d), Fire Clay.	III. A(a), Ball.	IA. (a), China Clay.	? Shale.	I. A(a), Semi-ball.	III. A(c), Semi-ball Refractory.	VI. A(a), Stoneware White.	XII. A(a), Stoneware Red.	XI. A(b), Terra-cotta.	I. A(a), China Clay.
	%	%	%	%	%	%	%	%	%	%
SiO_2	48·06	48·69	46·51	50·34	51·43	61·92	65·45	61·39	56·80	45·57
Al_2O_3	36·83	29·19	38·12	31·97	33·94	26·09	21·53	18·12	19·88	38·28
Fe_2O_3	·11	1·77	·40	2·68	·93	·75	·94	8·74	7·16	·56
FeO	*Nil*	·56	*Nil*	n.d.	n.d.	...	·12	·12	...	·14
MnO	tr.	·04	*Nil*	...	*Nil*	...	·09	·11	...	*Nil*
MgO	·18	·38	*Nil*	·86	*Nil*	·27	·71	1·00	·41	·14
CaO	·06	·06	·09	·16	*Nil*	*Nil*	*Nil*	tr.	·74	*Nil*
Na_2O	·17	·01	·12	·22	·37	·26	·31	·40	2·25	·20
K_2O	·58	·16	·32	2·66	·36	·74	1·69	1·98	1·92	·91
NaCl	·24	·03	·16	...	·17	tr.	...	...	·46	·27
TiO_2	·98	4·52	·62	...	·51	·54	n.d.	n.d.	...	·30
CO_2	*Nil*	·11	*Nil*	...	...	...	...	...	...	·02
P_2O_5	...	·02	...	...	...	...	...	...	...	·14
SO_3	...	·02	·05	...	·24	*Nil*	...	...	...	·01
H_2O +	12·75	12·10	13·68	9·73	11·32	8·64	7·34	6·38	10·50	13·11
H_2O —	·72	2·07	·50	1·16	·78	1·48	1·96	2·16	·47	·56
Humus	*Nil*	·24	*Nil*	...	...	...	...	...	...	·22
Others	...	·09*	...	...	·06†	...	...	...	...	*Nil*
Total	100·68	100·05	100·57	99·78	100·11	100·69	100·14	100·40	100·59	100·43
Analyst	Bowley	Grace	Bowley	Bowley	Murray	Murray	Simpson	Simpson	Robertson	Saw
Appendix IV No.	35	74	5	...	7	...	...	...	...	8

* Cr_2O_3, 0·02 ; V_2O_3, 0·07. † Water soluble salts.

APPENDIX I.—ANALYSES OF WESTERN AUSTRALIAN CLAYS—*continued.*

No.	31	32	33	34	35	36	37	38	39	40	41
Locality	Westonia.		Wilga.		Kalgoorlie.			Kanowna.			
Economic Class	Miloschite.		I. A(c), Refractory Ball Clay.	XII., Terra-cotta.	XI., Kaolinised Lodestuff.	I. A(c), Cornish Stone.	III. A(a), Stone-ware.	I. A(a), Cornish Stone.	I. B, Cornish Stone.	III. A(a), Cornish Stone.	A., Auriferous Alluvium.
	%	%	%	%	%	%	%	%	%	%	%
SiO_2	46.38	45.98	56.15	63.61	56.85	69.41	45.04	66.94	77.23	77.21	44.16
Al_2O_3	37.57	38.53	30.92	15.45	13.66	21.08	37.76	21.96	15.96	15.17	30.38
Fe_2O_3	.06	.05	.33	2.90	11.79	.24	.44	.15	traces	.13	4.44
FeO	*Nil*	*Nil*	...	3.10	5.38	*Nil*	*Nil*	...	...	...	...
MnO	*Nil*	*Nil*	...	.14	*Nil*	*Nil*	*Nil*	...	...	...	*Nil*
MgO	.36	.19	tr.	2.66	2.69	tr.	.15	.03	...	.15	.70
CaO	*Nil*	*Nil*	*Nil*	*Nil*	.47	.02	*Nil*	*Nil*	...	*Nil*	.53
Na_2O	.04	.02	.35	.43	.97	.14	3.77	.67	.14	1.00	1.05
K_2O	.07	.05	1.05	4.87	1.50	2.91	1.22	2.19	2.74	2.41	.33
NaCl	*Nil*	*Nil*	.12	tr.	.10	.31	1.42	.88	...	.79	...
TiO_2	*Nil* †	*Nil* †	.62	.76	1.51	.14	1.06	.20	...	.24	3.74 ?
CO_2	*Nil*	*Nil*	*Nil*	.04	.08	*Nil*	*Nil*	*Nil*	...	...	...
P_2O_5	n.d.	n.d.	n.d.	.22	.35	n.d.	n.d.	n.d.	...	...	...
SO_3	n.d.	n.d.	n.d.	n.d.	.10	n.d.	(.31)	.05¶	...	.01¶	...
H_2O + ...	13.75	13.91	10.53	4.20	4.00	5.32	7.93	6.70	3.36	2.63	11.80
H_2O —	.98	.89	.53	1.77	.58	.42	.92	.26	...	.10	3.81
Humus	*Nil*	*Nil*	...	.28	*Nil*	*Nil*	*Nil*	*Nil*	...	...	...
Others	1.22‡	1.01‡	.06*	tr. §	.06‖	.07*	.41*	.25*	...	.25*	...
Total	100.43	100.63	100.66	100.43	100.09	100.04	100.12	100.28	99.43	100.09	100.94
Analyst	Simpson.	Simpson.	Gillies.	Murray.	Simpson.	Gillies.	Bowley.	Gillies.	Gillies.	Rowledge.	Williams.
Appendix IV., No. ...	...	...	23	...	...	20	1–75	4	...	...	...

* Water soluble salts. † Rutile 0.57 deducted from 31; Rutile 0.32 deducted from 32. ‡ Cr_2O_3. § FeS_2. ‖ Cr_2O_3, 0.06; V_2O_3, *Nil*. ¶ In 38 SO_3 as alunite, 0.05; also 0.08 in water soluble salts. In 40 SO_3 as alunite, 0.01; also 0.06 in water soluble salts.

APPENDIX II.

CLASSIFICATION OF WESTERN AUSTRALIAN CLAYS.

Class I.	....	Pure White (Colour after 1,150°C.).
Class II.	....	Good White (do.)
Class III.	....	Creamy White (do.)
Class IV.	....	Greyish White (do.)
Class V.	....	Light Cream (do.)
Class VI.	....	Strong Cream (do.)
Class VII.	....	Light Buff (do.)
Class VIII.	....	Strong Buff (do.)
Class IX.	....	Pinkish Buff (do.)
Class X.	....	Dark Grey (do.)
Class XI.	....	Terra Cotta and Light Red (after 1,150°C.).
Class XII.	....	Dark Red and Brown (do.)

Sub Class for all Classes.	A.	Clay substance +	finest grit	over 90	per cent.
	B.	Do.	do.	80—90	,,
	C.	Do.	do.	70—80	,,
	D.	Do.	do.	60—70	,,
	E.	Do.	do.	50—60	,,
	F.	Do.	do.	40—50	,,

APPENDIX III.

LOCALITIES OF CLAYS TESTED.

Locality.	Registered No. and Classification of Clays.	Remarks.
Albany	7897 (IIIC.)	
Armadale ...	5109/33 (IIA.), 4584 (XA.)	
Arthur River ...	7501 (IIIA.)	
Balkuling ...	9637 (IIA.), 6635 (IID.), 1329/23 (IIIA.)	
Balla Balla ...	7901 (IIA.)	
Bannister ...	1833 (VA.)	
Bardoc	2294/25 (IIIA.)	
Bassendean ...	4370 (XIIA.), 2007/33 (VIIIA.)	
Beenup	... ...	See Cardup.
Bellevue	1862 (IIID.)	
Berring	8837 (IIB.), 8876 (IIB.)	
Beverley ...	1972 (IIIA.)	
Bibilup	4939/29 (IID.), 4938/29 (IVA.)	
Boddington ...	2308/25 (IIIA.), 1964/25 (XIIA.)	
Bolgart	1555 (IIA.)	
Boulder	... ...	See Kalgoorlie.
Boyanup ...	1692 (XIC.), 1691 (XIIC.), 1690 (XIIE.)	
Boyup Brook ...	1121/25 (IIC.), 1120/25 (IIIC.)	
Bridgetown ...	2103 (XIIC.)	
Broad Arrow ...	534/24 (IIIB.)	
Brookton ...	2794 (IIA.)	
Bullaring ...	2728/23 (IID.), 2729/23 (XIID.), 2727/23 (XIIE.)	
Bullsbrook ...	467/24 (XIIA.)	
Burabadgi ...	2457 (IA.)	
Burswood ...	277/24 (XIIA.)	
Busselton ...	80/27 (IIA.), 1584/25 (IIIB.), 2531/28 (XIIC.), 2530/28 (XIID.), 2532/28 (XIID.)	
Calcarra	1762 (ID.)	
Cannington ...	2019 (XIIE.)	
Capercup ...	3197/33 (IIIA.)	
Cardup	7510 (IB.), 3819 (IIIA.), 7797 (IIIA.), 7190 (VA.), 7511 (VID.)	
Carmel	1407 (VIIC.), 1479 (XC.)	
Chidlow	2527 (VE.)	
Clackline ...	2741/26 (IA.), 2742/26 (IIX.), 2190/27 (IIIA.), 2567/24 (IIIX.), 2569/24 (IIIX.), 2570/24 (IIIX.), 2573/24 (IIIX.), 2576/24 (VIIIX.)	
Collie	1471 (IA.), 1646 (IA.), 1899 (IA.), 6702 (IA.), 288/25 (IA.), 1575 (IIA.), 5598 (IIA.), 5661/33 (IIA.), 8232 (IIC.), 1384 (IIIA.), 1472 (IIIA.), 1516 (IIIA.), 6703 (IIIA.), 6704 (IIIA.), 3886/27 (IIIA.), 1653 (IVC.), 5597 (VA.), 1698 (VIIB.), 7113 (VIIIA.), 468/24 (IXA.), 5207 (XA.), 5744 (XA.), 5745 (XIA.), 1514 (XIIA.), 5739 (XIIA.), 5746 (XIIA.), 5596 (XIIB.)	
Coolgardie ...	3455 (IIA.), 1831 (XIA.)	
Coolup	1429 (XIIA.), 2039 (XIIA.), 1423 (XIIC.), 1424 (XIIE.)	
Cranbrook ...	1464 (VIIIA.)	
Cunderdin ...	70/25 (IB.)	
Dangin	1579/26 (IA.)	
Darlington ...	... ...	See Glen Forrest.
Denmark ...	1408 (VIC.), 1757 (VIIA.), 1756 (IXB.), 1891 (IXB.)	
Donnybrook ...	1513 (IID.), 4587 (VD.)	
Dowerin	7177 (IID.)	
Duranillin ...	3078/24 (IIA.)	

APPENDIX III.—*continued*.

LOCALITIES OF CLAYS TESTED—*continued*.

Locality.	Registered No. and Classification of Clays.	Remarks.
Dwellingup ...	435/27 (IIA.)	
Elgin	1658 (IIA.)	
Ferguson ...	1546 (IA.)	
Galena	5280/32 (IIB.)	
Gingin	1400 (IXA.)	
Glen Forrest ...	3045 (IA.), 1859 (IIA.), 3514 (IIA.), 1861 (IID.), 1900 (IID.), 1743 (IIID.), 3513 (IIID.), 1860 (IIIF.), 3315 (VB.), 2196 (VD.), 2445 (VD.)	Includes Darlington.
Goomalling ...	701/32 (IA.), 1753 (IIA.), 8543 (IIA.), 5391/31 (IIA.), 5390/31 (IIIA.)	
Gosnells	2073/24 (IVB.), 2074/24 (VIB.), 2075/24 (XIIA.)	
Greenmount ...	4362/29 (XIIC.)	
Gutha	10221 (IIA.)	
Harvey	1453/27 (IIID.)	
Jacob's Well ...	1922 (IC.), 2016 (IIIA.)	
Jandakot ...	2923 (XIIC.)	
Jimperding ...	5107/34	
Kalamunda ...	4160 (IB.), 4158 (IIA.), 4159 (IIA.), 1390 (IIB.), 1550 (IIB.), 2241 (IIIB.), 4161 (?C.), 4162 (?E.)	
Kalgoorlie ...	1470 (IA.), 1697 (IA.), 1767 (IA.), 2117 (IIA.), 4340 (IIA.), 1013/29 (IIA.), 2100 (IIIA.), 4183 (IIIA.), 2101 (IIIB.), 4036 (III?.), 1736 (IVA.), 2102 (IVA.), 3622 (VA.), 1832 (VIA.), 4035 (VIA.), 3250 (VIIA.), 1549 (XC.), 2199 (XIA.), 2281 (XIA.)	Includes Boulder.
Kanowna ...	2051 (IA.), 1732 (IB.), 2903/27 (IIA.), 2609/27 (IIA.), 1393/28 (IIA.), 2052 (IIB.), 2050 (IIIA.), 1394/28 (IIIA.), 1853 (IVA.), 1854 (VIA.), 1855 (VIB.), 1856 (XIB.), 1852 (XIIA.), 1898 (XIIA.)	
Kelmscott ...	2207 (VIB.), 2160 (XIC.), 2197 (XIIB.),	
Kendenup ...	1592/26 (IIB.)	
Kojonup ...	9261 (IIA.)	
Kondut	1766 (IIIE.)	
Kundip	1966/25 (VA.), 1965/25 (VA.)	
Kunjin	4166E (IA.), 4222E (IA.)	
Maddington ...	7260 (IIID.)	
Mambellup ...	7404 (XIA.)	
Manjimup ...	8043 (IIIA.)	
Meckering ...	195/26 (IA.)	
Merredin ...	4062 (XIB.), 1074/23 (XIIC.)	
Minnivale ...	1634/29 (IID.)	
Moora	1659 (XIIA.)	
Mt. Hardy ...	1687/26 (IIA.)	
Mt. Helena ...	563/31W (IIA.), 1041/31 (IIB.), 563/31 (IID.)	
Mt. Kokeby ...	1362 (IA.), 1430 (IA.), 3385 (IIA.), 2498/30 (IIA.), 3611 (IIIA.)	
Mujar	1389 (IIIA.)	*See* also Collie.
Mundijong ...	3307/24 (IVB.), 1388 (XIIA.), 2038 (XIIA.)	
Narrogin ...	8341 (IIID.), 8340 (XIIB.), 8339 (XIIC.)	
Newlands ...	3062 (VIA.), 3061 (XIIA.), 3063 (XIIA.)	
Ora Banda ...	2648/26 (IIIA.)	
Piawaning ...	8974 (IA.), 6322 (IIIA.)	
Pingelly	454/24 (IC.), 457/24 (IB.), 1982/29 (IID.), 1427 (IIID.), 456/24 (XD.), 458/24 (XE.), 455/24 (XE.), 1428 (XIID.)	
Pingrup	1463/25 (IA.) 444/25 (IIIC.)	
Pinjarra	2629 (IIE.)	
Popanyinning ...	1592 (IVD.), 1810/23 (XIIA.)	

APPENDIX III.—*continued.*

LOCALITIES OF CLAYS TESTED—*continued.*

Locality.	Registered No. and Classification of Clays.	Remarks.
Quairading ...	2222/23 (IA.)	
Ravensthorpe ...	2536 (IIIC.)	
Smith's Mill ...	... ...	*See* Glen Forrest.
Tambellup ...	8233 (IIIA.), 3396 (VIIA.)	
Tenterden ...	2055 (IIE.), 2112 (IIE.), 2046 (IIF.), 2749/27 (IIIB.), 2045 (XIC.), 8482 (XIIA.), 8483 (XIIA.)	
Three Springs ...	1970 (ID.), 3176 (I?.), 3174 (IID.), 3175 (IID.), 2010 (XIIA.), 2009 (XIIC.)	
Toodyay ...	198/31 (IXB.)	
Totadgin ...	8073 (IXD.)	
Victoria Park ...	2162 (XIIA.), 2161 (XIIB.)	
Wagin	9000 (IA.), 2399/31 (IA.), 2626/23 (XIIC.)	
Walebing ...	2166 (IIIE.)	
Wannamal ...	1854/32 (IIIA.)	
Wardering ...	7169 (IIIB.)	
Waroona ...	1396 (XIA.)	
Wicherina ...	7717 (XIA.)	
Wilga	2111 (IA.)	
Woodlupine ...	8879 (IIIA.), 8880 (IIIA.), 8881 (IIIA.), 2333 (VIA.)	
York	7503 (XIIB.), 7502 (XIID.), 7504 (XIID.), 7357 (XIID.)	
Youraling ...	8537 (IIA.)	
Yuna	1568 (IIIA.), 1569 (IVA.), 8788 (VIA.), 8906 (VIA.), 1570 (XA.), 1979 (XA.), 4132 (XIA.)	

APPENDIX IV.

PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS.

N.B.—In this Table the figure for plasticity is that obtained by Ashley's method using malachite green dye.

In the colour scheme p.w. is pure white, g.w. is good white, cr. w. is creamy white.

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class 1A. (a)—			%		%	°C.	%	%			
1	Clackline Loc. 171	Refractory china clay	C.S. 91·9	17	5·2	1,050	3·4	27·2	p.w.	..	
			— 90 7·9		...	1,150	5·4	25·8	p.w.		
			— 60 ·1		...	1,250	6·6	22·3	p.w.	....	
			+ 60 ·1			1,350	10·7	13·5	cr. w.	Incipient	
2	Collie C.M.L. 245	Plastic fireclay ...	C.S. 99·2	52	6·6	1,050	·5	54·5	p.w.	....	Much coaly matter.
			— 90 ·5		....	1,150	5·1	44·5	p.w.		
			— 60 ·3		....	1,250	5·6	45·4	cr.w.		
			+ 60 tr.		..	1,350	9·9	34·1	cr.w.	Incipient	
3	Glen Forrest, Statham's .... Pit	Levigated china clay	C.S. 100·0	28	7·1	1,050	5·3	23·1	p.w.	No vitrification	Prepared from kaolinised granite.
			— 90 —		....	....	....	....	...	....	
			— 60 —		...	....	....	....	....	....	Analysis No. 18.
			+ 60 —		...	....	....	....	..	....	
4	Kanowna Alunite, P.A. 506	Fluxing clay (Cornish stone)	C.S. 91·5	20	2·6	1,050	·9	29·7	p.w.	..	Analysis No. 38.
			— 90 4·3		...	1,150	2·2	27·3	p.w.	....	
			60 2·8		.	1,250	5·1	20·5	p.w.	Incipient	
			+ 60 1·4		..	1,350	6·0	14·7	cr. w.	.	
5	Kunjin Locs. 12446/7	China clay ...	C.S. 95·2	20	2·9	1,050	4·1	36·6	p.w.	..	Analysis No. 23.
			90 4·0			1,150	4·6	35·3	p.w.		
			60 ·4		..	1,250	9·6	22·3	p.w.	Incipient	
			+ 60 ·4		...	1,350	16·4	13·1	cr. w.	..	
6	Meckering Loc. 22233 ...	Refractory ball clay	C.S. 90·3	78	8·3	1,050	2·2	31·6	p.w.	....	Black spots at 1,350°.
			— 90 9·6		....	1,150	3·6	28·8	p.w.		
			60 ·1			1,250	12·0	14·2	cr. w.	Incipient	
			+ 60 tr.			1,350	13·6	10·1	cream	.	
7	Mt. Kokeby Loc. 16114	Semi-ball	C.S. 91·9	50	5·5	1,050	8·6	28·6	p.w.	....	Analysis No. 25.
			— 90 7·8		....	1,150	9·9	24·7	p.w.	....	
			— 60 ·2			1,250	13·4	17·0	p.w.	Incipient	
			+ 60 ·1		...	1,350	11·8	11 3	g.w.	.	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued.*

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA.—*continued.*											
8	Wagin Loc. 3533	China clay	C.S. 90·7	24	4·2	1,050	2·8	40·3	p.w.	...	Analysis No. 30.
			— 90 9·1		...	1,150	4·5	35·5	p.w.		
			[illegible]			[illegible]	[illegible]	[illegible]	p.w.	Incipient	
			[illegible]			[illegible]	[illegible]	12·6	p.w.		
Class IA. (b)—											
9	Capercup Loc. 3198 ...	Ball clay (refractory)	C.S. 88·6	75	9·2	1,050	2·7	28·6	p.w.	...	
			— 90 1·6			1,150	4·7	25·2	p.w.		
			— 60 1·7			1,250	[illegible]	12·0	p.w.		
			+ 60 8·1			1,350	11·8	9·8	cr. w.	Incipient	
10	Clackline, adjacent Loc. 19453	Fireclay	C.S. 84·9	22	8·2	1,050	5·0	42·7	p.w.	....	Specked at 1,350°.
			— 90 14·0		...	1,150	4·7	41·9	p.w.	...	
			— 60 ·8		.	1,250	8·5	33·1	p.w.		
			+ 60 ·3			1,350	15·1	19·7	g.w.	Incipient	
11	Collie, C.M.L. 245	Ball clay	C.S. 81·9	64	7·2	1,050	3·2	25·4	p.w.		
			— 90 17·6			1,150	5·4	20·8	p.w.		
			— 60 ·4			1,250	7·6	18·1	p.w.	Incipient.	
			— 60 ·1			1,350	[illegible]	12·2	cr. w.		
12	Goomalling Loc. 17248	Fireclay	C.S. 82·7	30	4·2	1,050	3·5	38·4	p.w.		
			— 90 12·7		....	1,150	3·8	37·3	p.w.	..	
			— 60 1·4		...	1,250	7·2	29·9	g.w.	...	
			+ 60 3·2		....	1,350	9·0	25·5	g.w.	No vitrification	
13	Jimperding, Yinniding Creek	Fireclay	C.S. 80·7	?	3·9	1,050	....	....	....	...	
			— 90 16·9		.	1,150	5·0	....	p.w.	....	
			- 60 2·3		....	....	....	...	....	....	
			+ 60 ·1		....	....	....	....	....	....	
14	Mokine, Loc. 4185	Fireclay	C.S. 87·3	26	6·2	1,050	4·1	41·4	p.w.	.	
			— 90 11·3			1,150	4·3	40·5	p.w.		
			— 60 ·4			1,250	7·0	34·0	p.w.		
			+ 60 1·0			1,350	12·3	24·0	g.w.	Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued.*

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA. (b)—*continued.*											
15	Paddington, adjacent Railway Station	Semi-ball	% C.S. 80·8 — 90 18·4 — 60 ·1 + 60 ·7	34	% 1·5	° C. 1,050 1,150	% ... 1·4 ...	% ... 15·2	.. p.w.		
16	Piawaning, Loc. ?	Semi-ball	C.S. 89·4 — 90 10·2 — 60 ·1 + 60 ·3	50	8·9	1,050 1,150 1,250 1,350	2·7 5·2 13·3 15·0	31·0 26·0 10·7 8·1	p.w. p.w. g.w. g.w.	.. ... Incipient ..	
17	Wagin, Loc. 3533	Semi-ball	C.S. 89·5 — 90 9·5 — 60 ·2 + 60 ·8	30	3·7	1,050 1,150 1,250 1,350	3·4 4·3 9·7 14·7	37·1 34·6 24·0 11·5	p.w. p.w. p.w. g.w.	... ... Incipient	
18	Westonia, Gold P.A. 3356 ..	Semi-ball fireclay ...	C.S. 80·2 — 90 16·6 — 60 1·0 + 60 2·2	46	4·7	1,050 1,150 1,250 1,350	2·8 4·6 7·6 9·4	38·0 33·8 27·5 23·3	p.w. p.w. g.w. g.w.	.... No vitrification	
Class IA. (c)—											
19	Holland Soak—Two miles South of	Fireclay ...	C.S. 72·3 — 90 23·0 — 60 1·3 + 60 3·4	20	1·4	1,050 1,150 1,250 1,350	3·5 3·8 6·2 7·7	42·8 42·2 35·3 32·6	p.w. p.w. p.w. p.w.	. ... .. No vitn. at 1,350°	Highly refractory.
20	Kalgoorlie, Gold P.A. 902 .	Fluxing (Cornish stone)	C.S. 72·5 — 90 21·8 — 60 3·4 + 60 2·3	14	2·6	1,050 1,150 1,250 1,350	*nil* .... 7·4 ..	29·1 ... 14·0 ...	p.w. . p.w. ...	.. ... Advanced ..	Analysis No. 36.
21	Kalgoorlie, P.A. 902 ...	Fluxing (Cornish stone)	C.S. 75·9 — 90 15·9 — 60 2·4 + 60 5·8	14	2·1	1,050 1,150 1,250 1,350	... 3·0 3·6 7·2	... 17·5 18·9 10·5	.. p.w p.w. p.w.	. . Incipient Advanced	

Appendix IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued.*

No.	Sample.	Type.	Texture.	Plasticity.	Air shrinkage.	Temperature.	Fire shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA. (c)—*continued.*											
22	Kalgoorlie, P.A. 902	Fluxing (Cornish stone)	C.S. 72·8	14	2·1	1,050	1·3	22·4	p.w.	....	
			— 90 25·9			1,150					
			— 60 ·8			1,250	3·8	20·1	p.w.	Incipient	
			+ 60 ·5			1,350	9·9	6·6	p.w.	Advanced	
23	Wilga, Coal P.A. 263 ..	Refractory semi-ball	C.S. 76·1	54	7·4	1,050	·4	30·8	p.w.	....	Analysis No. 33.
			— 90 19·0			1,150	3·2	29·3	p.w.	....	
			— 60 4·1			1,250	6·0	21·6	p.w.		
			+ 60 ·8			1,350	8·4	16·6	g.w.	No vitn. at 1,350	
Class IA. (d) and (e)—											
24	Burabadji, adjoining Loc. 7807	China clay ..	C.S. Fine-	12	3·9	1,050	3·9	39·0	p.w.	..	Requires grinding. Analysis No. 5.
			— 90 grained			1,150	6·0	34·2	p.w.	...	
			— 60 but not			1,250	11·9	21·0	p.w.	Incipient	
			+ 60 friable			1,350	15·6	12·1	w. spotted		
25	Collie, Premier C.M.	Semi-ball clay	C.S. 67·9	50	8·1	1,050	2·6	32·1	p.w.	....	
			— 90 30·8			1,150	3·5	31·3	p.w.	....	
			— 60 ·3			1,250	13·2	13·2	lt. cr.	Incipient	
			+ 60 1·0			1,350	14·4	10·2	lt. cr.		
26	Collie, Loc. 1382	Siliceous fireclay ...	C.S. 48·3	24	3·6	1,050	·2	22·1	p.w.	....	Flint substitute.
			— 90 42·1			1,150	·3	21·5	p.w.		
			— 60 2·5			1,250	1·4	19·1	c.w.	....	
			+ 60 7·1			1,350	1·5	18·1	c.w.	No vitn. at 1,350	
27	Dangin Loc. 13096 ...	Fireclay	C.S. 67·1	39	5·4	1,050	3·1	45·0	p.w.		
			— 90 31·0			1,150	4·4	43·4	p.w.	....	
			— 60 1·0			1,250	12·3	26·7	g.w.	....	
			+ 60 ·9			1,350	14·5	20·9	g.w.	Incipient	
28	Ferguson, Loc. 1983 ..	Semi-ball	C.S. 54·2	40	4·2	1,050	*nil*	22·8	p.w.	.	Flint substitute.
			— 90 44·2		....	1,150	·5	23·4	p.w.	....	
			— 60 ·7		....	1,250	2·0	21·2	cr.w.	....	
			+ 60 ·9		....	1,350	2·8	18·8	cr.w.	Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued.*

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage	Porosity	Colour.	Vitrification.	Remarks.
Class IA. (d) and (e)—											
			%		%	C.	%	%			
29	Quairading, Loc. 11008	Semi-refractory	C.S. 54·7	34	2·8	1,050	3·1	32·8	p.w.		
			90 38·1			1,150	3·4	31·3	p.w.		
			60 1·4			1,250	12·1	15·6	cr.w.	Incipient	
			60 5·8			1,350	13·2	11·5	cr.w.		
Class IB. (a)—											
30	Kanowna, P.A. 506 ...	Semi-ball refractory	C.S. 84·8	40	3·6	1,050	·1	31·2	p.w.		
			90 2·5			1,150	·3	31·5	p.w.		
			60 6·8			1,250	5·1	12·4	p.w.		
			60 5·9			1,350				Incipient at 1,300	
Class IB. (b)											
31	Cardup, West of Brickworks	Ball clay	C.S. 71·4	69	9·5	1,050	3·3	31·1	p.w.		
			90 14·1			1,150	4·4	29·2	p.w.	Incipient	
			60 2·3			1,250	9·5	18·2	cr.w.		
			60 12·2			1,350	11·5	12·9	cr.w.		
32	Kalamunda, Piesse Gully	Fireclay	C.S. 73·3	10	7·9	1,050					
			90 11·9			1,150					
			60 7·9			1,250					
			60 6·9			1,350	12·7	9·7	p.w.	Incipient	
Class IB. (c)—											
33	Cunderdin—Nine miles South-East of	Fireclay	C.S. 66·5	22	3·8	1,050	4·0	48·1	p.w.		Yields good china clay by levigation.
			90 22·5			1,150	4·7	47·2	p.w.		
			60 5·7			1,250	9·3	35·2	p.w.		
			60 5·3			1,350	12·8	28·2	p.w.	No vitn. at 1,350	
34	Pingelly, West Brook	Plastic Fireclay	C.S. 67·8	54	2·8	1,050	2·3	42·2	p.w.		
			90 19·6			1,150	5·3	35·3	p.w.		
			60 7·8			1,250	12·2	19·5	g.w.		
			60 4·8			1,350	16·2	12·8	g.w.	Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued.*

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
	Class IC. (d)										
			%		%	C.	%	%			
35	Jacob's Well Loc.	Fireclay	C.S. 68·1	25	6·8	1,050	3·2	38·5	p.w.	....	Analysis No. 21.
			— 90 11·1			1,150	6·8	31·5	p.w.		
			— 60 9·2			1,250	6·4	29·5	cr.w.	....	
			+ 60 11·6			1,350	12·1	17·0	cr.w.	Incipient	
	Class IIA. (a)—										
36	Armadale, Loc. 88 and 91	Semi-ball	C.S. 90·7	53	8·9	1,050	4·5	39·4	g.w.	....	Kaolin vermicular.
			— 90 5·4			1,150	5·6	30·9	g.w.	....	
			— 60 ·8			1,250	8·6	24·3	g.w.	Incipient	
			+ 60 3·1			1,350	12·2	16·3	cr.w.		
37	Balkuling, Loc. 11098	Semi-ball	C.S. 90·1	46	7·6	1,050	2·2	37·4	g.w.		
			90 7·4			1,150	3·1	34·1	g.w.	....	
			— 60 ·6			1,250	9·1	20·5	cr.w.	Incipient	
			60 1·9			1,350	13·3	11·8	cr.w.		
38	Balla-Balla—One mile from wharf	Refractory semi-ball	C.S. 99·0	50	5·8	1,050	....	....	....		
			— 90 ·1			1,150	1·7	37·2	g.w.		
			— 60 ·1			1,250	5·2	26·8	cr.w.	....	
			+ 60 ·8			1,350	4·3	27·1	cr.w.	No vitn. at 1,350	
39	Bolgart, Lot No. 7	Ball clay	C.S. 94·4	73	11·1	1,050	5·4	30·7	p.w.	....	Analysis No. 4.
			— 90 1·4			1,150	5·0	31·6	g.w.	....	
			60 1·4			1,250	10·9	19·1	g.w.	Incipient	
			+ 60 2·8			1,350	16·8	6·2	lt.cr.		
40	Brookton, Loc. 10138	Semi-ball	C.S. 98·3	65	7·9	1,050	6·6	25·5	g.w.	....	
			— 90 ·2			1,150	7·0	21·4	g.w.	Incipient	
			— 60 ·1			1,250	11·5	15·1	cr.w.		
			+ 60 1·4			1,350	15·2	8·3	cr.w.		
41	Coolgardie, G.M.L. 2173	China clay refractory	C.S. 96·8	25	2·8	1,050	3·1	37·3	g.w.		
			— 90 ·5			1,150	4·8	38·8	g.w.	....	
			— 60 1·6			1,250	7·5	30·5	g.w.	....	
			+ 60 1·1			1,350	7·7	28·3	cr.w.	No vitn. at 1,350°	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIA. (a)—*continued*.			%		%	° C.	%	%			
42	Elgin, Loc. 234	Ball clay	C.S. 92·4	75	11·8	1,050	2·9	24·2	p.w.	...	Analysis No. 17.
			— 90 6·0			1,150	4·0	22·6	g.w.	Incipient	
			— 60 1·3			1,250	13·1	5·2	cr.w.	...	
			+ 60 ·3			1,350	13·5	4·3	cream	Advanced	
43	Glen Forrest, Statham's Pit	China clay refractory	C.S. 96·9	25	4·5	1,050	3·0	37·1	g.w.	...	Analysis No. 19.
			— 90 1·2			1,150	3·8	36·7	g.w.		
			— 60 1·1			1,250	6·0	29·6	cr.w.	...	
			+ 60 ·8			1,350	10·0	22·7	lt.cr.	Incipient	
44	Glen Forrest	Semi-ball	C.S. 98·3	60	9·2	1,050	4·6	34·5	g.w.	.	
			90 ·5			1,150	8·9	22·5	g.w.	.	
			60 ·9			1,250	14·4	12·3	g.w.	.	
			60 ·3			1,350	16·5	8·4	cream	Incipient	
45	Goomalling, Stink Well	Semi-ball	C.S. 95·1	59	8·3	1,050	3·9	28·1	g.w.	...	Analysis No. 20.
			90 1·3			1,150	7·3	20·1	g.w.	Incipient	
			60 ·1			1,250	14·4	8·7	cr.w.	.	
			60 ·5			1,350	15·9	5·7	cr.w.	.	
46	Goomalling, Stink Well	Ball	C.S. 94·3	75	8·6	1,050	4·4	24·5	p.w.	...	
			— 90 4·5			1,150	7·0	19·0	g.w.	Incipient	
			— 60 ·2			1,250	14·1	4·9	cream	...	
			60 1·0			1,350	15·1	3·9	cream	Advanced	
47	Mt. Kokeby, Loc. 16114	Semi-ball	C.S. 91·9	57	5·3	1,050	2·8	29·1	g.w.		
			— 90 7·9			1,150	5·6	24·1	g.w.	...	
			— 60 ·2			1,250	9·7	15·7	g.w.	Incipient	
			60 tr.			1,350	11·3	12·2	cr.w.		
48	Mt. Kokeby, Loc. 16114	Semi-ball	C.S. 98·2	54	14·6	1,050	5·0	35·5	g.w.		
			90 1·7			1,150	7·6	31·3	g.w.		
			60 *nil*			1,250	15·1	14·7	cr.w.	Incipient	
			60 ·1			1,350	19·0	6·9	cream		
49	Youraling, Loc. 7454	Semi-ball	C.S. 92·8	50	9·5	1,050	2·7	31·2	p.w.		
			— 90 6·1			1,150	8·6	20·6	g.w.	Incipient	
			— 60 ·1			1,250	9·7	13·9	cr.w.		
			+ 60 1·0			1,350	16·3	6·9	cream		

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued.*

No	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIA. (b)											
			%		%	°C.	%	%			
50	Collie, between C. and Wellington Mills	Ball Stoneware	C.S. 88·5	80	7·5	1,050	3·6	30·6	g.w.		
			90 6·8			1,150	5·5	26·0	g.w.		
			60 1·3			1,250	14·3	9·1	cr.w.	Incipient	
			60 3·4			1,350	16·7	5·1	cr.w.	Advanced	
51	Duranillin	Ball	C.S. 83·2	98	9·6	1,050	3·9	30·4	g.w.		
			90 16·0			1,150	6·6	25·1	g.w.		
			60 ·5			1,250	11·5	13·9	cr.w.	Incipient	
			60 ·3			1,350	14·9	11·4	cream		
52	Dwellingup Loc. 1121	Semi-ball	C.S. 83·4	48	9·8	1,050	3·7	37·9	g.w.		Black Spots.
			90 12·3			1,150	4·3	34·5	g.w.		
			60 1·6			1,250	13·3	18·3	cr.w.	Incipient	
			60 2·7			1,350	13·6	17·8	cr.w.		
53	Goomalling, Stink Well	Semi ball	C.S. 84·9	66	5·0	1,050	1·5	26·0	p.w.		
			90 12·7			1,150	5·5	19·0	g.w.	Incipient	
			60 2·3			1,250	6·7	15·5	cr.w.		
			60 ·1			1,350	9·2	11·9	lt.grey		
54	Jimperding, Yinniding Creek	Fireclay	C.S. 85·5	28	4·7	1,050	4·9	38·9	g.w.		
			90 14·3			1,150	5·2	38·3	g.w.		
			60 ·1			1,250	7·3	33·5	p.w.		
			60 ·1			1,350	12·7	21·9	p.w.	Incipient	
55	Kalamunda, Piesse Gully	Fireclay	C.S. 89·7	40	7·6	1,050	3·4	29·5	g.w.		
			90 7·4			1,150	3·3	25·3	g.w.		
			60 1·4			1,250	6·5	20·7	cr.w.		
			60 1·5			1,350	10·6	14·8	cr.w.	Incipient	
56	Kalgoorlie, G.M.L. 350	Stoneware Cornish stone	C.S. 83·5	73	2·6	1,050	3·0	27·4	g.w.		
			90 8·0			1,150	5·1	18·3	g.w.		
			60 3·2			1,250	7·6	10·2	cr.w.	Incipient	
			60 5·3			1,350	14·1	4·1	gr.w.	Advanced	
57	Kalgoorlie, Adj. G.M.L. 3391	Fireclay	C.S. 89·0	31	5·3	1,050	·5	34·8	p.w.		
			90 5·9			1,150	2·8	27·2	g.w.		
			60 1·7			1,250	7·0	21·9	cr.w.		
			60 3·4			1,350	11·4	11·6	cr.w.	Incipient	

APPENDIX IV. PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIA. (b)—*continued*.			%		%	°C.	%	%			
58	Kalgoorlie — Seven miles North of	Stoneware	C.S. 83·0	9	1·1	1,050	*Nil*	24·5	g.w.	....	"Grit," mostly mica.
			— 90 17·0		....	1,150	2·6	18·8	g.w.	Incipient	
			— 60 *nil*			1,250	11·0	2·5	grey	Advanced	
			+ 60 *nil*			1,350	11·2	·9	grey	....	
59	Kanowna, M.C. 6	Stoneware Cornish stone	C.S. 88·2	1	0·7	1,050	·2	n.d.	p.w.	....	"Grit," mostly mica.
			— 90 11·6		....	1,150	5·6	21·1	g.w.	Incipient (1,200°)	
			— 60 ·1			1,250	16·5	·8	gr.w.	Advanced	
			+ 60 ·1			1,350	16·7	·5	cr.w.	....	
60	Kanowna, M.C. 10	Stoneware Cornish stone	C.S. 88·1	9	2·7	1,050	4†	34·8	g.w.	....	"Grit," mostly mica.
			— 90 11·1		....	1,150	3·3	26·8	g.w.	....	
			— 60 ·2		....	1,250	10·1	13·2	cr.w.	Incipient	
			+ 60 ·6		....	1,350	14·7	1·0	cr.w.	Advanced	
61	Kojonup	Semi-ball	C.S. 87·7	62	11·5	1,050	4·5	32·4	g.w.	....	
			— 90 8·8		....	1,150	6·0	30·2	g.w.	....	
			— 60 1·4			1,250	13·0	15·3	cr.w.	Incipient	
			+ 60 2·1			1,350	14·7	12·1	cr.w.		
62	Mt. Hardy	Fireclay	C.S. 85·4	36	5·3	1,050	3·6	38·7	g.w.	....	
			— 90 14·6		....	1,150	4·9	35·7	g.w.	....	
			— 60 tr.		....	1,250	12·5	20·4	cr.w.	Incipient	
			+ 60 *nil*			1,350	15·9	13·5	cream	....	
Class IIA. (c)—											
63	Busselton—Fourteen miles South-East of	Ball clay or Fullers' earth	C.S. 71·9	154	14·9	1,050	4·9	42·8	g.w.	....	Refractory.
			— 90 26·5		....	1,150	9·0	32·7	g.w.	....	
			— 60 ·8		....	1,250	12·7	21·9	cr.w.	Incipient	
			+ 60 ·8		....	1,350	15·2	18·5	cream	....	
64	Collie-Cardiff Lot 283	Semi-ball	C.S. 77·3	53	6·2	1,050	·7	24·1	g.w.	....	Refractory.
			— 90 17·7		....	1,150	3·4	20·3	g.w.	....	
			— 60 1·8		....	1,250	6·9	14·1	cr.w.	Incipient	
			+ 60 3·2		....	1,350	7·2	13·4	cr.w.	....	

† Increase.

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—continued.

No.	Source.	[illegible]	[illegible]	[illegible]	Air [illegible] age.	Temperature.	Fire [illegible] age.	[illegible]	[illegible]	[illegible]	[illegible]
Class IIA. (c)—continued.											
65	Gutha Loc. 5523 ...	Fireclay	[illegible]	22	% 4·7	°C 1,050	[illegible]	[illegible]	[illegible]		
			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	No vit. at 1,350	
66	Mt. Helena, 2½ miles from Railway Station	Ball clay stoneware	C.S. 77·3	100	8·6	1,050	[illegible]	[illegible]	[illegible]	[illegible]	Partly levigated from [illegible]
			— 90 21·3			1,150	[illegible]	[illegible]	[illegible]		
			— 60 1·1			1,250	[illegible]	[illegible]	[illegible]	Advanced	
			— 60 ·3			1,350	[illegible]	[illegible]	[illegible]		
Class IIB. (a)—											
67	Kalamunda, Piesse Gully	Fireclay	[illegible]	40	7·6	1,050	[illegible]	[illegible]	[illegible]		
			[illegible]			1,150	[illegible]	[illegible]	[illegible]	Incipient	
			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]			1,350	[illegible]	[illegible]	[illegible]		
68	Kanowna M.L. 47 ...	Stoneware	[illegible]	[illegible]	0·8	1,050	[illegible]	[illegible]	[illegible]		
			[illegible]			1,150	[illegible]	[illegible]	[illegible]		
			[illegible] 1·8			1,250	[illegible]	[illegible]	[illegible]	Incipient	
			[illegible] 5·6			[illegible]	[illegible]	[illegible]	[illegible]	Advanced	
69	Kendenup Lake bed	Coarse semi-ball clay	C.S. 81·8	40	[illegible]	[illegible]					
			[illegible] 2·4			1,150	[illegible]	[illegible]	[illegible]		
			[illegible] 3·2			[illegible]					
			— [illegible] 12·[illegible]			[illegible]					
Class IIIA. (a)—											
70	Beverley, East, Loc. 5784 ...	Fireclay	C.S. 96·[illegible]	[illegible]	[illegible]	1,050	3·9	34·6	[illegible]		
			— 90 1·[illegible]			1,150	7·6	24·0	[illegible]		
			— 60 2·[illegible]			1,250	7·7	24·0	[illegible]		
			— 60 [illegible]			1,350	12·3	16·6	cr.w.	Incipient	
71	Cardup Lot 47 244 ...	Ball	C.S. 93·3	76	[illegible]	1,050	·3	35·6	cr.w.	[illegible]	Analysis No. 9.
			— 90 2·3			1,150	·3	34·8	[illegible]		
			— 60 1·9			[illegible]	·2	22·1	[illegible]		
			— 60 2·5			1,350	·6	19·7	[illegible]		

APPENDIX IV. PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasticity.	Air Shrinkage.	Temperature.	Fire Shrinkage.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIIA. (a)—											
			%		%	C.	%	%			
72	Capercup—Seven miles South of	Ball	C.S. 92·1	92	11·2	1,050	3·5	24·9	g.w.	Incipient	
			- 90 ·5			1,150	4·3	22·5	cr. w.		
			60 ·4			1,250	10·1	14·5	cr.w.		
			- 60 7·0			1,350	10·7	11·7	cr.w.		
73	Collie C.M.L. 245	Fireclay	C.S. 93·6	14	5·3	1,050	1·1	31·4	lt. pink		
			90 5·3			1,150	3·9	29·5	cr.w.		
			- 60 ·3			1,200	7·7	21·3	cr.w.		
			+ 60 ·8			1,250	9·7	18·2	cr.w.		
74	Kalamunda-Woodlupine Brook	Ball stoneware ...	C.S. 90·0	104	14·9	1,050	3·1	29·6	g.w.	....	Analysis No. 22.
			— 90 7·7			1,150	7·8	21·3	cr.w.	Incipient	
			60 ·9			1,250	16·3	6·3	pale grey	...	
			60 1·4			1,350	16·9	4·5	pale grey	Advanced	
75	Kalgoorlie, half-mile North-West of Central Battery	Stoneware	C.S. 96·8	*Nil*	1·8	1,050	3·5	33·7	cr.w.	....	Analysis No. 37.
			90 3·0			1,150	9·6	17·0	cr.w.	Incipient	
			- 60 ·2			1,250	17·3	1·9	lt. grey	Advanced	
			+ 60 *nil*			1,350	18·9	1·0	lt. buff		
76	Kanowna P.A. 506	Stoneware	C.S. 95·8	3	2·6	1,050	*nil*	26·6	p.w.	....	
			90 2·1			1,150	8·1	12·3	cr.w.	Incipient	
			- 60 1·6			1,250	13·6	1·1	g.w.	Advanced	
			60 ·5			1,350	11·3	0·7	g.w.		
77	Manjimup Loc. 48/2034	Semi-ball	C.S. 92·4	54	11·8	1,050	4·5	38·9	cr.w.		
			- 90 5·4			1,150	4·7	37·6	cr.w.		
			60 [illegible]			1,250	17·4	11·9	buff	Incipient	
			+ 60 1·5			1,350	17·4	10·1	buff	...	
78	Piawaning Loc. 39 ...	Semi-ball	C.S. 92·9	47	7·3	1,050	3·5	30·1	g.w.		
			90 7·1			1,150	5·1	24·1	cr.w.	Incipient	
			60 *nil*			1,250	13·1	12·9	cr.w.		
			+ 60 *nil*			1,350	15·7	7·9	cr.w.		

GENERAL INDEX.

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